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TYPES OF PODS OF ASCLEPIAS SYRIACA FOUND IN MICHIGAN[1]

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INTRODUCTION

In recent years there has been a growing interest in the seed floss of various species of *Asclepias*. This interest was accentuated by the outbreak of war which cut off our primary source of kapok, the East Indies. As has been noted in numerous popular and semiscientific accounts,[2] the seed floss of several species of *Asclepias* has been found to be an adequate substitute for kapok in the manufacture of life preservers as well as for other uses.

The purpose of the present paper is to give an account of biological observations made primarily on the ubiquitous and most important floss-yielding species, the common milkweed (*Asclepias syriaca* L.). Although the ultimate success of a program of floss production on a commercial scale is still a matter of speculation, nevertheless the information derived from such studies as these will, it is hoped, be of assistance in the evaluation of the economic future of *A. syriaca*, as well as in stimulating purely botanical interest in a truly remarkable group or plants.

As will be recalled, *Asclepias syriaca* is a perennial herbaceous plant whose renewed seasonal growth is accomplished by the sprouting of one or more adventitious buds on its widespread root system. The flowers, borne in dense umbels, are, according to some, the most highly specialized in respect to entomophily of all the dictoyledons. Two (rarely three) pistils are produced by each flower, only one of which ordinarily becomes a mature fruit. Botanically, this fruit is considered a follicle, i. e., a fruit composed of a single carpel which dehisces along a ventral suture. Commonly, however, it is referred to as a "pod."

No one interested in the species can fail to be impressed by the striking variations in type of pods produced. Nor can this seemingly infinite variety be correlated with environment, for within a relatively

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[2] WHITING, A. G. A SUMMARY OF THE LITERATURE ON MILKWEEDS (ASCLEPIAS SPP.) AND THEIR UTILIZATION. U. S. Dept. Agr. Bibliog. Bul. 2, 41 pp. 1943.

restricted area many types may occur. As illustrative of this, one may compare the "Toma" types and the "Petoskey"–222–254 types illustrated in this paper. Both groups were obtained from limited areas in widely separated localities in Michigan, and by no means exhaust the variety of types found at these sites.

MATERIALS AND METHODS

The pods on which the present study was based were all collected in the Lower Peninsula of Michigan. Extensive collections were made over a period of 2 years in Washtenaw, Jackson, and Livingston Counties in the southern part of the peninsula and in Emmet County in the northern part. In addition, less extensive collections were made in Clinton, Gratiot, Isabella, Clare, Roscommon, Crawford, Otsego, Charlevoix, and Cheboygan Counties.[3]

It was essential that the pods be studied as soon after collection as possible and that in the interim they be stored in a cold, moist room. This was necessary because as they dried their characteristic shape and ornamentation was usually lost to a large degree. A study of dried material as, for example, that found on a herbarium sheet, would be of little value in showing the striking differences in pod types which exist. As a further aid, representative pods were photographed as well as drawn.[4]

Types are given designations consisting of a locality combined with a number. There are so many of these types and they occur so mixed in the same populations that they do not appear to be entities that should be given more formal names. From an agronomic standpoint any strains that prove to have outstanding value can be known by the locality designations.

GENERAL FEATURES OF THE POD

For the purposes of this study, two extremes of pod types have been recognized. These are based on the general shape of the pod as it appears from the side with the suture side (ventral) lowermost.

The first of these types is illustrated by such pods as Roscommon-30 (fig. 1, *A*), Harbor Springs-1 (fig. 1, *B*), and Dexter-1 (fig. 1, *K*). These might be described as "plump" varieties having a low ratio of length to diameter, with rounded base and short-snouted apex. In lateral aspect the dorsal and ventral contours are concave and opposed. The other extreme of type recognized is represented by pods of Stockbridge-11 (fig. 5, *I*), Petoskey-104 (fig. 5, *D*) and Roscommon-22 (fig. 4, *I*). Here, there is a distinct, more or less tapering base and prolonged apex, the contours in lateral view being variable in types, often sigmoidal. The whole structure is distinctly subfusiform in shape with the greatest diameter below the equatorial region. The ratios of length to diameter in these types are the highest found. In all pods the place of attachment of the fruit to the pedicel appeared as a more or less well developed bump or papilla.

[3] Collections in the southern part of the State were made by Dr. Norma L. Pearson as well as by the writer.

[4] All drawings are to the same scale and were made from living material by Mrs. Mary Bernard Klepper under the supervision of the writer.

Between these two extremes are large numbers of intermediate types which grade almost imperceptibly toward one or the other limit. The whole classification is recognized as being a purely utilitarian one and is intended to serve as a framework for an orderly description of the pod types selected from a large population and, in addition, for a study of possible differences in floss characteristics.

In addition to the general shape of the pod, there are other external features that often differ markedly in pods from different clones. Of these, the ornamentation of the pod is the most striking. Some pods (in the writer's experience, relatively few), such as Toma-58 (fig. 2, *F*) and Winans Lake-31 (fig. 4, *A*) are almost completely smooth. By far the great majority of the types, however, bear external processes of some sort. These are usually found surmounting more or less conspicuous ridges, very rarely occuring in the hollows between ridges. These processes varied from low "nubbins" to pronounced spines, which might be short, as in Roscommon-30 (fig. 1, *A*), of slightly greater length, as in Petoskey-200 (fig. 1, *F*), or of extraordinary length, as in Petoskey-244 (fig. 2, *I*) and Ypsilanti-5 (fig. 3, *H*). They may be straight as in Ypsilanti-5, apically directed as in Roscommon-30, or, as in Otsego-12 (fig. 2, *J*), North Territorial-1 (fig. 1, *H*), and Petoskey-110 (fig. 4, *C*), they may be variously directed, hooked, and "shaggy." Differences in the frequency of occurrence of the spines on the pod are quite noticeable. Two extremes are provided by Toma-3 (fig. 3, *A*), and Petoskey-222 (fig. 3, *E*), the former bearing a moderate number on wide-spaced ridges, the latter, by reason of the density of the spines, assuming a somewhat "hedgehog"-like aspect.

Other features which lend distinctiveness to the fruits are enumerated in the descriptions which follow. Two, of striking appearance, might be especially mentioned. The first of these is the presence of anthocyanin pigment of a purple hue. This pigmentation may consist of only a faint streaking, confined to the fruits alone, or, as in Toma-5 and Harbor Springs-17, it may be very intense and extend to the stem and midribs of the leaves. No particular study was made of this feature. It was noted, however, that during at least two growing seasons, certain clones, as, for example, Toma-5, were constant in this respect. As may be expected in a "sun-red" pigment, light modifies it and a pod developing tightly against a stem will have a streak on it free of pigment. A second feature is the peculiar "rumpling" found primarily in such types as Toma-5 (fig. 2, *A*), Houghton-1, (fig. 4, *J*), and Toma-10 (fig. 3, *J*). This is not an abnormal feature of one or several pods, to be explained perhaps by abortive development or premature drying; it is a constant characteristic of all the pods of a plant and of all pods belonging to plants of a single clone. In the case of Toma-5 it has been followed through two growing seasons in the field as well as under greenhouse conditions and has remained constant.

All the fruits collected were more or less tomentose. In some the pubescence was minute or closely felted and inconspicuous, whereas in others, such as Petoskey-110, it was so woolly as to give a shaggy aspect to the pod. In color, the fruits ranged from pale to very deep green. As indicated previously, some were very strongly suffused with purple, so much so, as in Harbor Springs-17, that they appeared nearly black.

DESCRIPTION OF PODS

Roscommon–30 (fig. 1, *A*).—Plump, with rounded base, by reason of broad irregular depressions appearing somewhat rumpled, apex short, abruptly tapering, slightly upturned; 61 × 33 mm., ratio 1.9:1; tomentose, very yellow green suffused with purple; ridges low, wide-spread, closer together on the ventral side, provided with nubbins and short, apically directed spines.

With Harbor Springs–1 representative of the plumpest types found.

Harbor Springs–1 (fig. 1, *B*, *C*).—Plump, with rounded base, even contour, not rumpled, apex somewhat prolonged, very slightly upturned; 71 × 33 mm., ratio 2.2:1; conspicuously tomentose, light yellow green tinged with red; ridges very inconspicuous, wide-spaced, spines few, low with broad bases, nearly obsolete on the dorsal surface, a few near the apex.

Distinct because of the smooth dorsal surface and few, coarse ventral spines.

Petoskey–246 (fig. 1, *D*).—Plump, with rounded base, even contour, not rumpled, apex short, blunt, straight or very slightly dorsally upturned; 63 × 28 mm., ratio 2.3:1; tomentose, green tinged with purple; ridges numerous, straight, low except at the apex, knifelike, bearing many threadlike, variously oriented, sometimes hooked spines.

A plump, spiny, small, "snub-nosed" type.

St. Johns–15 (fig. 1, *F*).—Plump, with rounded base, even contour, apex somewhat prolonged, slightly dorsally upturned; 57 × 25 mm., ratio 2.3:1; tomentose, very pale green, ridges very faint, spines small, very short, confined to a few on the ventral surface.

A small, nearly smooth type.

Petoskey–200 (fig. 1, *E*).—Plump, intermediate type with abruptly tapering base, even contour, and conspicuously blunt, straight snub-nosed apex; 73 × 32 mm., ratio 2.3:1; conspicuously tomentose, very pale green; ridges low, inconspicuous, close together, covered with numerous coarse, moderately long, apically-directed straight spines.

A very snub-nosed coarse spiny type.

Stockbridge–5 (fig. 1, *G*).—Somewhat plump, rounded base, even contour, apex stout, short, slightly dorsally upturned; 76 × 31 mm., ratio 2.5:1; tomentose, pale green; ridges broad, very low, nearly obsolete, with a few small low nubbins scattered over the ventral surface.

A plump nearly smooth type resembling the preceding one.

North Territorial–1 (fig. 1, *H*).—Plump, tending to intermediate type, with rounded base, even contour, straight, somewhat prolonged apex; 87 × 34 mm., ratio 2.6:1; tomentose, very pale green tinged with purple; ridges numerous, closely spaced, inconspicuous, spines long, frequently hooked, appearing "combed," the tips very frequently basally directed.

A plump type with numerous shaggy, often basally directed hooked spines.

Toma–25 (fig. 1, *I*).—Distinctly large, fat, puffy type, conspicuously rumpled throughout, with short, upturned apex; 103 × 39 mm., ratio 2.6:1; tomentose, yellow green; strongly ridged, the ridges broad and wide-spaced, appearing coarse, bearing numerous long, hooked, more or less apically directed spines which impart a shaggy appearance to the nod.

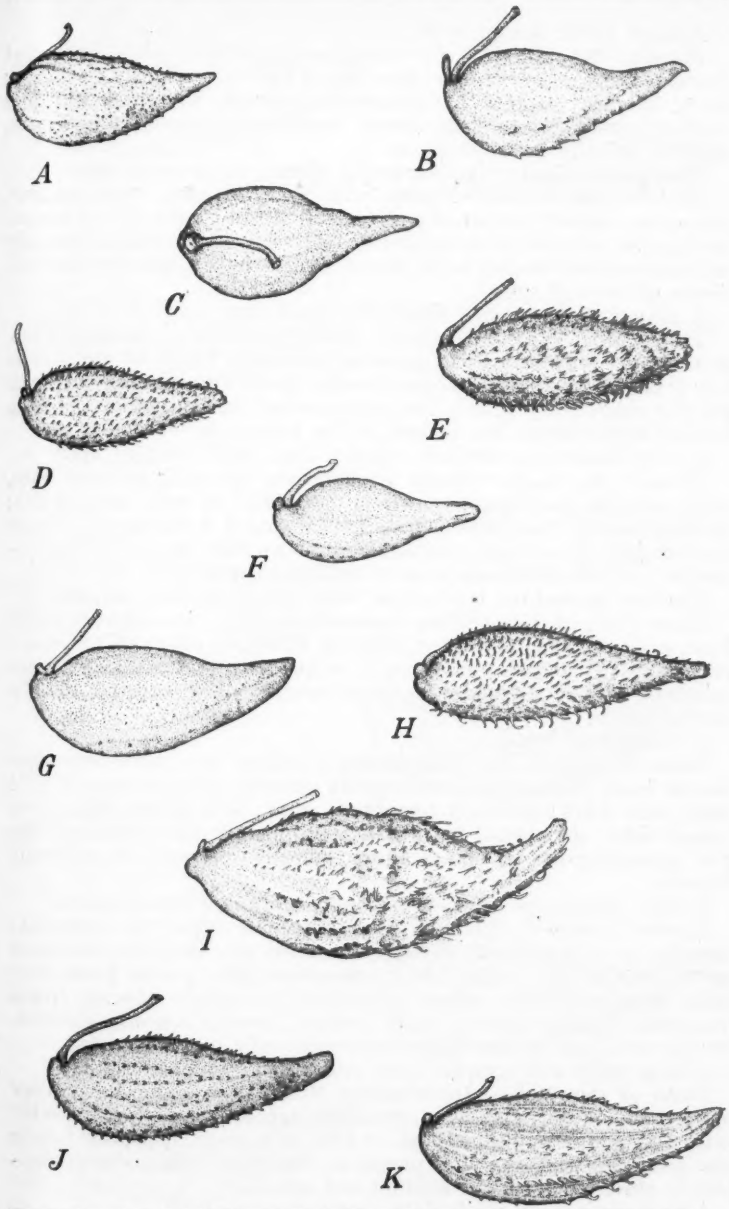

FIGURE 1.—Types of pods of *Asclepias syriaca;* all lateral view except *C*: *A*, Roscommon–30; *B*, Harbor Springs–1; *C*, Harbor Springs–1, dorsal view; *D*, Petoskey–246; *F*, St. Johns–15; *E*, Petoskey–200; *G*, Stockbridge–5; *H*, North Territorial–1; *I*, Toma–25; *J*, Petoskey–248; *K*, Dexter–1. One-half natural size.

A large, puffy, shaggy type.

Petoskey–248 (fig. 1, *J*).—Intermediate type, with somewhat rounded base, even contour, apex short and very slightly upturned; 85 × 32 mm., ratio 2.7:1; tomentose, suffused with purple; ridges inconspicuous, rather wide-spaced, bearing numerous conspicuous, slender, apically-directed spines.

A moderate sized, trim, somewhat plump, snub-nosed type.

Dexter–1 (fig. 1, *K*).—Plump, with rounded base, even contour, and stout, slightly upturned apex; 91 × 34 mm., ratio 2.7:1; tomentose, green, suffused with purple; strongly ridged, the ridges unevenly wide-spaced and bearing large, coarse, wedge-shaped, apically directed, distinctly hooked spines.

A plump, coarse-spined distinctly ridged type.

Toma–5 (fig. 2, *A*).—Distinctly plump, puffy type, rounded base, apex short, conspicuously rumpled or puckered; 92 × 34 mm., ratio 2.7:1; densely tomentose, almost woolly, green, strongly suffused with purple; ridges very broad, low, ornamented with nubbins and long hooked spines which are densest on the ventral surface.

A very distinctive strongly run-red type with rumpled apex.

Toma–1 (fig. 2, *B*).—Plump intermediate type with rounded base, even contour, and short, upturned apex; 81×29 mm., ratio 2.8:1; inconspicuously tomentose, grass green tinged with purple; ridges narrow, low, numerous, ornamented with nubbins and short, wedge-shaped, apically directed spines of moderate density.

A rather generalized type of pod with few distinctive features.

Toma–9 (fig. 2, *C*).—Plump intermediate type, somewhat rounded base, even contour, and short, slightly upturned apex; 88×31 mm., ratio 2.8:1; tomentose, gray green; ridges narrow, numerous, inconspicuous, densely covered with sharp, long, apically directed, slightly curved spines.

A "hedgehog" type.

Toma–11 (fig. 2, *D*).—Intermediate plump type with somewhat narrow base, even contour, moderately tapering straight apex; 70×24 mm., ratio 2.9:1; sparingly tomentose, light, clear green; ridges very conspicuous, sometimes blackened, occasionally anastomosing, the pod appearing fluted, spines short, apically directed, of moderate density.

A trim, fluted type with low, strongly apically directed spines.

Epsilon Church–6 (fig. 2, *E*).—Intermediate type with somewhat rounded or truncate base, distinctly rumpled near the short, upturned apex; 114×38 mm., ratio 3.0:1; tomentose, light yellow green with faint spots of purple; ridges prominent, irregularly spaced, spines numerous, coarse, tending to be hooked, usually apically directed, for the most part on the ridges but occasionally in the furrows.

A large puffy and rumpled type with numerous coarse spines.

Toma–58 (fig. 2, *F*).—Intermediate plump type, somewhat narrow base, even contour, and short, gradually tapering apex; 68×22 mm., ratio 3.1:1; minutely tomentose, at first dark green, becoming lighter and somewhat suffused with purple at maturity; ridges almost completely obsolete, devoid of nubbins and spines.

A very distinctive, small, dark green, spineless type.

Alanson–1 (fig. 2, *G*).—Intermediate type with abruptly narrowing base, even contour, and tapering, slightly upturned apex; 100×32

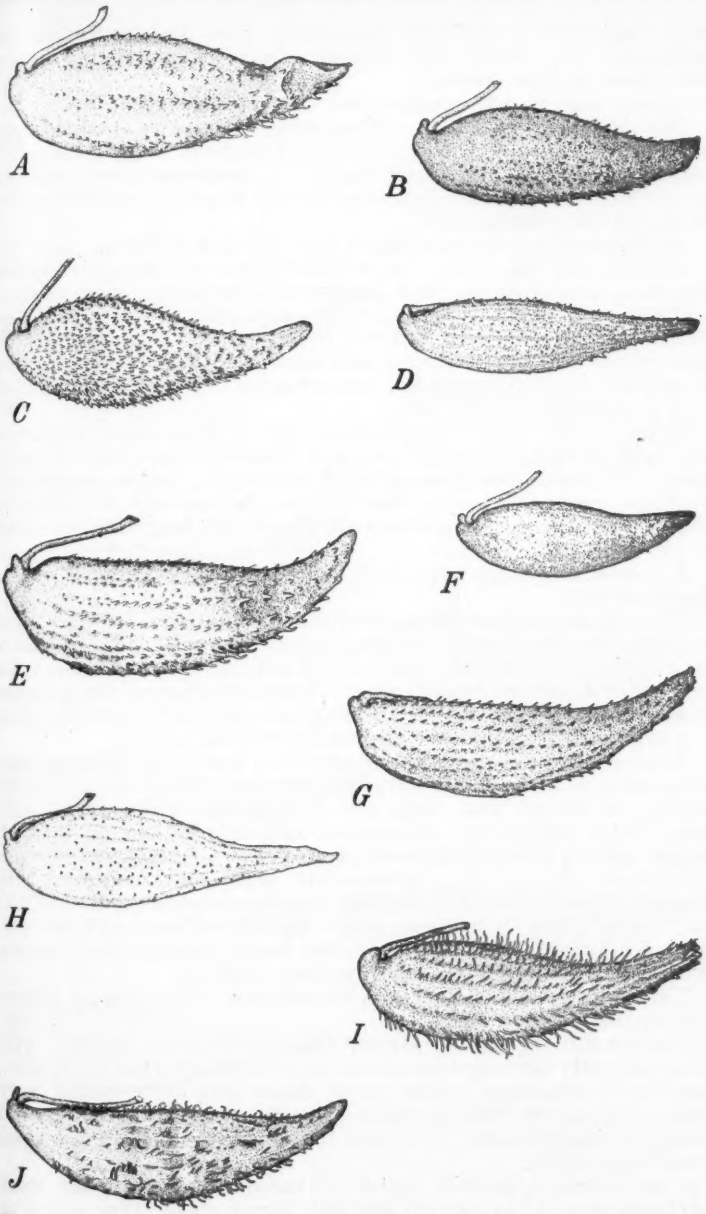

FIGURE 2.—Types of pods of *Asclepias syriaca;* all lateral view: *A*, Toma–5; *B*, Toma–1; *C*, Toma–9; *D*, Toma–11; *E*, Epsilon Church–6; *F*, Toma–58; *G*, Alanson–1; *H*, Stockbridge–2; *I*, Petoskey–244; *J*, Otsego–12. One-half natural size.

mm., ratio 3.1:1; distinctly tomentose, very dark purple; ridges numerous, low, closely and regularly spaced, spines short, slender, numerous, apically directed.

A large dark purple, conspicuously tomentose type.

Stockbridge–2 (fig. 2, *H*).—Intermediate type with rounded base, even contour, and somewhat prolonged straight or slightly upturned, tapering apex; 100×32 mm., ratio 3.1:1; tomentose, green suffused with purple along the ridges; conspicuously ridged, the ridges bearing scattered low nubbins.

An intermediate strongly ridged type with low nubbins.

Petoskey–244 (fig. 2, *I*).—Intermediate type with abruptly narrowing base, even contour, and prolonged, somewhat upturned apex; 102×32 mm., ratio 3.2:1; conspicuously tomentose, dark green; ridges numerous, narrow, and relatively inconspicuous except at the apex where they are prominent and bladelike, spines very long, erect or apically directed, straight or somewhat hooked, appearing combed.

A shaggy type.

Otsego–12 (fig. 2, *J*).—Intermediate type with a somewhat narrow base and abruptly tapering, puckered, upturned apex; 99×31 mm., ratio 3.2:1; tomentose, green suffused with purple; ridges conspicuous, knifelike, tending to become obsolete near the base and low ridges on the ventral surface, spines irregularly distributed, long, thin, variously oriented.

A somewhat shaggy type with high thin ridges primarily on the dorsal surface.

Toma–3 (fig. 3, *A*).—Plump intermediate type, rounded base, even contour, apex moderately tapering, somewhat prolonged, straight or slightly upcurved; 98×30 mm., ratio 3.3:1; silvery tomentose, grass green with a purplish tinge; ridges wide-spaced, narrow, conspicuous, mostly on the ventral surface, bearing scattered low incurved spines.

A type with the heaviest ridges on the ventral surface.

Toma–2 (fig. 3, *B*).—Plump intermediate type with rounded base, even contour, apex tapering, slightly puckered, not upturned or only slightly so; 95×29 mm., ratio 3.3:1; tomentose, very silvery, light green tinged with purple; ornamented with nubbins and low wedged-shaped apically directed spines which are denser on the ventral surface.

Brutus–9 (fig. 3, *C*).—Intermediate type, even contour, with abruptly tapering base and tapering, slightly upturned apex; 110×33 mm., ratio 3.3:1; tomentose, green slightly suffused with purple; ridges wide-spaced, conspicuous, rather broad, bearing short, coarse, sharp, occasionally hooked, apically-directed spines.

A stout intermediate type with conspicuous ridges bearing coarse, short spines.

Petoskey–240 (fig. 3, *D*).—Intermediate type, even contour, with rather abruptly tapering base and short truncate apex; 91 × 27 mm., ratio 3.4:1; tomentose, yellow green; ridges irregularly spaced, very pronounced on the ventral surface; spines numerous, coarse, and strongly apically hooked or reduced to nubbins, frequently in several rows on the ridges.

A snub-nosed type with spines of variable character, the most developed ones of the conventionalized "Greek wave" type.

Petoskey–222 (fig. 3, *E*).—Intermediate plump type, even contour, with long, tapering, strongly upturned apex distinctly differentiated

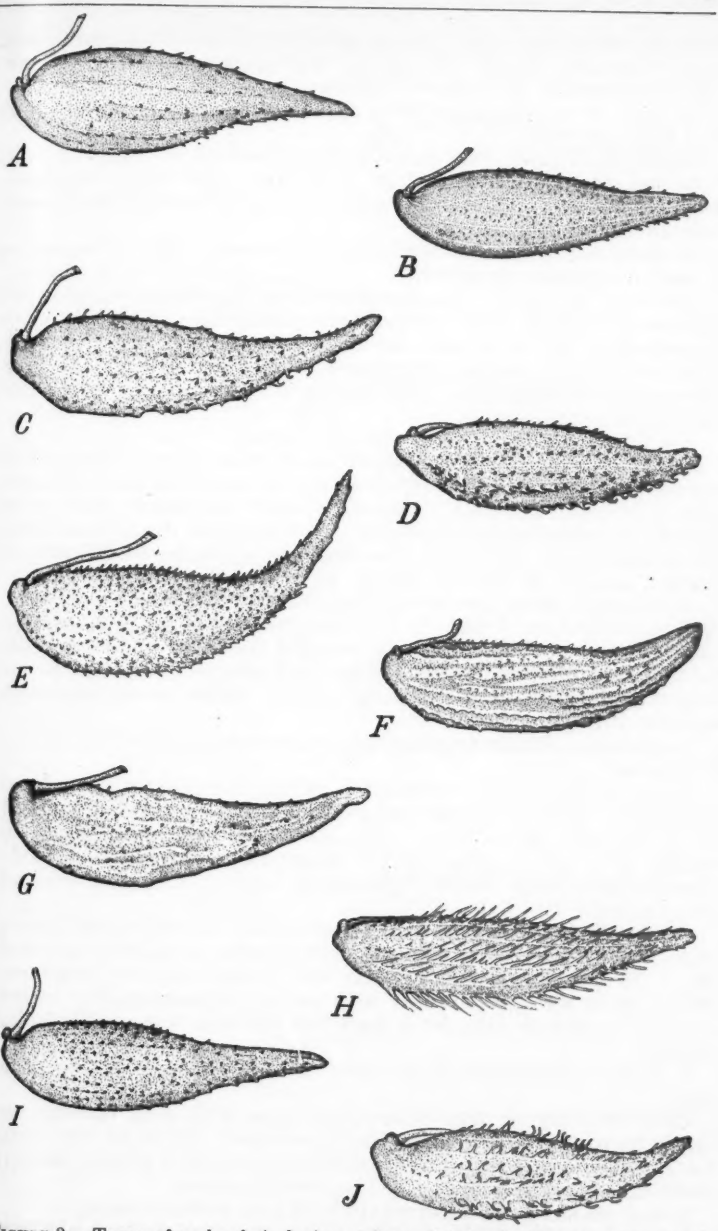

FIGURE 3.—Types of pods of *Asclepias syriaca;* all lateral view: *A*, Toma–3; *B*, Toma–2; *C*, Brutus–9; *D*, Petoskey–240; *E*, Petoskey–222; *F*, Ypsilanti–1; *G*, Dexter–2; *H*, Ypsilanti–5; *I*, Harbor Springs–17; *J*, Toma–10. One-half natural size.

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from the main body; 113×33 mm., ratio 3.4:1; tomentose, dark green, very obscurely ridged, the spines very numerous, short, narrow, apically directed, some merely nubbins.

A large intermediate hedgehog type with sharply separated body and apex.

Ypsilanti–1 (fig. 3, *F*).—Intermediate type with obliquely truncate base and stout upturned apex; 92 × 27 mm., ratio 3.4:1; tomentose, pale yellow-green; ridges broad and conspicuous bearing short, sharp, apically directed spines.

A coarse ridged type, somewhat lunate from the side and resembling a small misshapen cucumber.

Dexter–2 (fig. 3, *G*).—Intermediate type, somewhat rumpled and uneven in contour, with abruptly narrowing base and slightly upturned apex; 104 × 30 mm., ratio 3.5:1; inconspicuously tomentose, light yellow green, somewhat suffused with purple; strongly and irregularly ridged, depressions wide and of irregular depth, spines few, short, and inconspicuous.

A strongly ridged, large, intermediate type.

Ypsilanti–5 (fig. 3, *H*).—Intermediate type, even contour, with somewhat narrow base and tapering, slightly upturned truncate apex; 106 × 30 mm., ratio 3.5:1; inconspicuously tomentose, dark green, ridges numerous, narrow, bladelike, continuous to the truncate apex of the pod; spines numerous, of extraordinary length, the longest awl-shaped, straight or slightly curved, apically directed.

A strikingly spiny type resembling Petoskey- 244.

Harbor Springs–17 (fig. 3, *I*).—Intermediate type, even contour, somewhat rounded base, tapering, straight apex; 107 × 30 mm., ratio 3.6:1; tomentose, yellow green strongly suffused with very dark purple; ridges low, closely and regularly spaced, spines short, numerous, apically directed.

A somewhat slender very strongly anthocyanin type with numerous low spines.

Toma–10 (fig. 3, *J*).—Somewhat plump intermediate type with moderately tapering slightly upcurved apex, body somewhat rumpled; 86 × 24 mm., ratio 3.6:1; very tomentose, appearing distinctly woolly, grass green with purplish tinge; ridges narrow, low, wide-spaced, spines long, slender, straight or hooked, variously oriented, many apically directed.

Winans Lake–31 (fig. 4, *A*).—Intermediate to subfusiform slender type, narrow base, even contour, apex straight or slightly upraised; 90 × 25 mm., ratio 3.6:1; finely and densely silvery tomentose, yellow green strongly suffused with purple; inconspicuously ridged, completely smooth save for a very few, minute, low usually apical nubbins.

A highly characteristic spineless, silvery, strongly anthocyanin type.

Hankerd–3 (fig. 4, *B*).—Subfusiform type with even contour, abruptly narrowing base and straight, stout apex; 101 × 28 mm., ratio 3.6:1; tomentose, green, ridges low, numerous, spines narrow, apically directed, densest and longest on the ventral surface.

A medium-sized subfusiform type with long ventral spines.

Petoskey–110 (fig. 4, *C*).—Intermediate type, even contour, abruptly narrowing base and tapering, slightly upturned apex; 95×26 mm., ratio 3.7:1; very densely tomentose, light yellow green, slightly

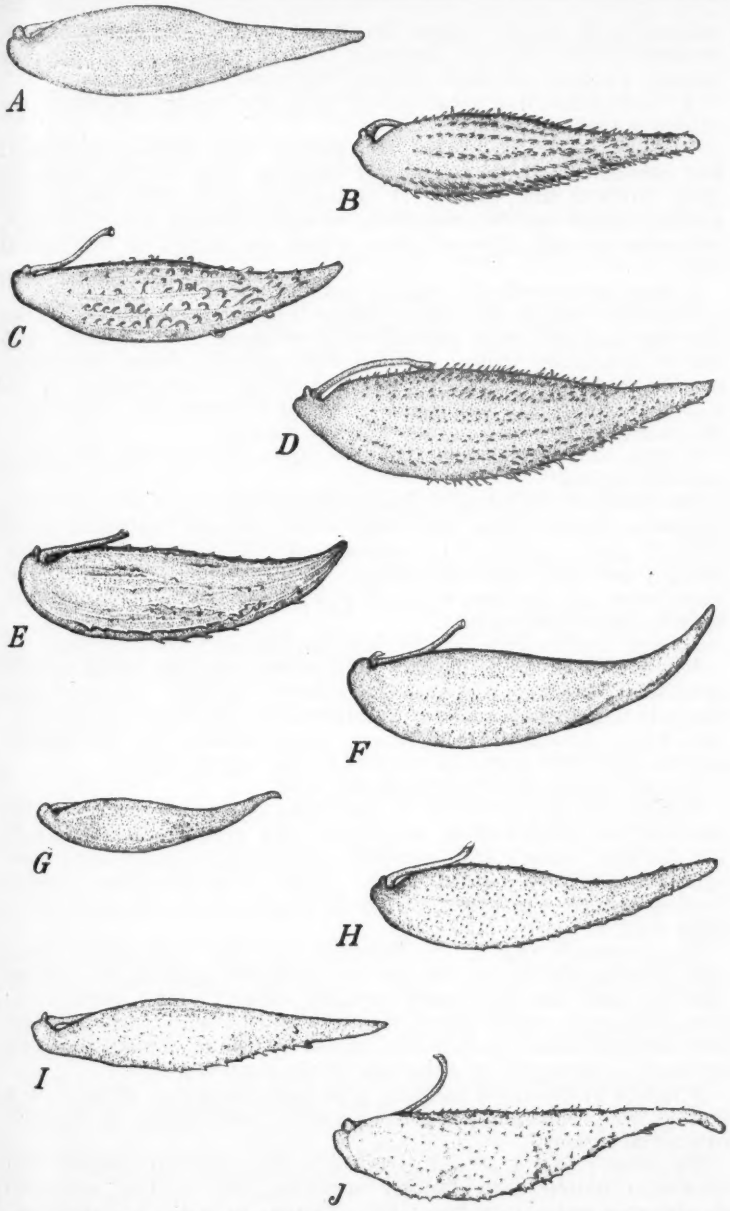

FIGURE 4.—Types of pods of *Asclepias syriaca;* lateral view: *A*, Winans Lake-31; *B*, Hankerd–3; *C*, Petoskey–110; *D*, Toma–4; *E*, Waterloo–6; *F*, Stockbridge–1; *G*, Patons Corners–17; *H*, Toma–6; *I*, Roscommon–22; *J*, Houghton–1. One-half natural size.

suffused with purple; ridges irregularly spaced, consisting of low, knifelike edges bearing somewhat widely spaced, long, strongly hooked, variously directed, densely tomentose, coarse spines.

A very distinctive intermediate pod, the woolly spines of the "Greek wave" type.

Toma–4 (fig. 4, *D*).—Large, intermediate type tending to be stout and subfusiform, with moderately tapering, long, slightly wrinkled apex; 119×32 mm., ratio 3.7:1; tomentose, grass green, tinged with purple; ridges narrow, numerous, straight, bearing many straight, somewhat apically directed spines which are longest on the ventral side.

A large, spiny pod with slightly rumpled apex.

Waterloo–6 (fig. 4, *E*).—Intermediate type, even contour, somewhat tapering base and short, slightly upturned apex; 107×28 mm., ratio 3.8:1; tomentose, green, suffused with purple; ridges prominent, narrow, knifelike, irregularly spaced, tending to anastomose, spines scattered, sparse, low and coarse, irregular in length and character, a few hooked, others more or less apically directed.

A type with conspicuous knifelike ridges and variably developed scattered spines.

Stockbridge–1 (fig. 4, *F*).—Intermediate type, with even contour, somewhat narrow base and long, stout, apically upturned apex; 108×27 mm., ratio 4.0:1; conspicuously tomentose, light green, strongly suffused with dark purple; inconspicuously ridged, depressions broad and shallow, with a few scattered low nubbins, particularly on the ventral surface.

A large, intermediate, nearly spineless, heavily pigmented type.

Patons Corners–17 (fig. 4, *G*).—Subfusiform type, the dorsal contour even and definitely sigmoid, the ventral, strongly concave, base abruptly tapering, apex moderately prolonged, upturned; 68×17 mm., ratio 4.0:1; tomentose, bright green; ridges obscure, the pod smooth, save for a few low scattered nubbins on the ventral surface.

A small, green, practically spineless type.

Toma–6 (fig. 4, *H*).—Slender, intermediate, subfusiform type, even contour, with a moderately prolonged, very slightly upturned apex; 102×25 mm., ratio 4.1:1; minutely and inconspicuously tomentose, light green with a reddish tinge; ridges numerous, low, slender, bearing low, erect or apically directed, slender, sharp spines in moderate density.

Roscommon–22 (fig. 4, *I*).—Subfusiform type, with narrow base, even contour, the dorsal contour very shallowly sigmoid, the ventral concave, apex tapering, nearly straight; 104×25 mm., ratio 4.2:1; tomentose, pale yellow green, slightly suffused with purple; ridges low, inconspicuous and numerous, spines few, short, apically directed, confined to the region on either side of the ventral suture.

A nearly symmetrical fusiform type with the spines confined to a limited area on either side of the suture, particularly in the subequatorial region.

Houghton–1 (fig. 4, *J*).—Intermediate type, strongly rumpled and uneven in contour, with abruptly narrowing, long tapering, contorted slender apex and narrow base; 107×25 mm., ratio 4.3:1; tomentose, light grass green; ridges coarse, pronounced, bearing numerous irregularly spaced, apically directed spines.

A conspicuously rumpled, "flabby" type with a long irregular apex which is sharply separated from the main body.

Petoskey–254 (fig. 5, *A*).—Subfusiform type, the dorsal contour shallowly sigmoid, the ventral nearly straight, base abruptly tapering, the apex prolonged, tapering, and nearly straight, the ventral surface conspicuously flattened; 108×25 mm., ratio 4.3:1; tomentose, very strongly suffused with purple; ridges low and very inconspicuous, bearing minute nubbins and, towards the apex, short, apically directed, fairly numerous spines.

A very dark purple type with strikingly broad, flat ventral surface; the spines nearly obsolete.

Toma–8 (fig. 5, *B*).—Slender, subfusiform type, with conspicuously long and tapering apex; 100×22 mm., ratio 4.5:1; silvery tomentose, grass green tinged with red; ridges numerous, narrow, very inconspicuous, bearing a few nubbins and short, mostly ventral, erect spines.

A nearly smooth type with prolonged apex.

St. Johns–30 (fig. 5, *C*).—Stout, subfusiform type, even contour, the ventral shallow, concave, the dorsal low and sigmoid, with a narrow base and long, tapering, upturned apex; 110×24 mm., ratio 4.6:1; tomentose, green; ridges fairly numerous, low, sharp, very pronounced at the apex, spines of moderate length and density, slender, apically directed, occasionally hooked.

A fairly stout subfusiform type with low, knifelike ridges which become very pronounced at the apex.

Petoskey–104 (fig. 5, *D*).—Long, slender, subfusiform type with a double sigmoid dorsal contour and concave ventral one, base narrow and prolonged, apex strongly tapering and prolonged; 109×23 mm., ratio 4.7:1; tomentose, green; ridges low, inconspicuous, ornamented with small, sometimes hooked, apically directed spines.

A long, fusiform type.

Burt Lake–6 (fig. 5, *E*).—Somewhat stout, subfusiform type, lunate in outline, with narrow base and long, tapering, upcurved apex; 114×24 mm., ratio 4.8:1; tomentose, grass green; ridges inconspicuous, numerous, closely spaced, narrow, spines slender, straight or hooked, variously oriented but tending to be apically directed.

A not very pronounced subfusiform type, distinctly lunate in outline.

Gaylord–2 (fig. 5, *F*).—Slender, subfusiform type, the dorsal contour sigmoid, the ventral very slightly concave, with a narrow base and tapering, nearly straight apex; 109×22 mm., ratio 5.0:1; very densely tomentose, pale yellow green; ridges numerous, low, narrow, bladelike, close together, spines fairly long, slender, apically directed, those on the ventral surface tending to be hooked.

A slender, densely tomentose type covered with numerous spines on low bladelike ridges.

Oden–3 (fig. 5, *H*).—Slender subfusiform type, somewhat rumpled, with a narrow base and slender, tapering, straight apex, ventral contour sigmoid, dorsal low and convex; 90×18 mm., ratio 5.0:1; densely tomentose, pale green, somewhat suffused with purple; ridges prominent, wide-spaced, without spines, except for a few scattered ones on the dorsal surface.

A slender, rumpled, strongly ridged, nearly spineless type.

Buck Lake–57 (fig. 5, *G*).—Slender subfusiform lunate type with narrow base and prolonged distinctly upturned apex; 109×22 mm.,

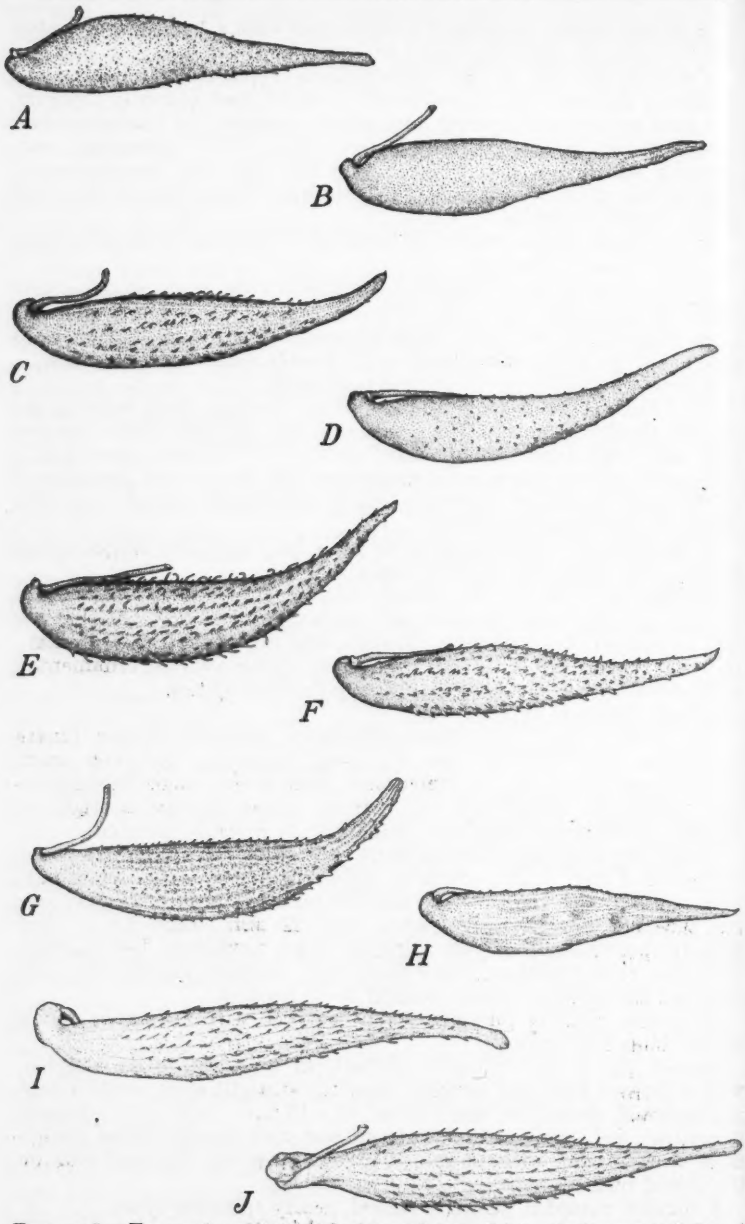

FIGURE 5.—Types of pods of *Asclepias syriaca;* all lateral view except *J*. *A* Petoskey–254; *B*, Toma–8; *C*, St. Johns–30; *D*, Petoskey–104; *E*, Burt Lake–6; *F*, Gaylord–2; *H*, Oden–3; *G*, Buck Lake–57; I, Stockbridge–11; *J*, Stockbridge–11, dorsal view. One-half natural size.

ratio 5:1; tomentose, light green, slightly suffused with purple, ridges numerous, narrow, spines short and wedgelike, of moderate density.

A very slender subfusiform, lunate type.

Stockbridge–11 (fig. 5, *I*, *J*).—Long, slender, subfusiform type, the dorsal contour a very shallow double sigmoid curve, the ventral concave, with a distinctly narrow prolonged base and nearly straight, long tapering apex; 125×21 mm., ratio 6.0:1; tomentose, pale green; ridges numerous, low, spines numerous, very slender, apically directed, hooked, some black.

A very long, slender type with numerous slender spines; the apex in some specimens turned downward.

DISCUSSION

The foregoing account of some pod types of milkweed found in Michigan involves several points of general interest.

Although collections were made from a considerable range of territory in the Lower Peninsula of Michigan, it should be emphasized that the pods described here by no means exhaust the diversity of types to be found. As has been previously indicated, at a favorable site many different types may occur. This was strikingly illustrated in the case of a 1-acre experimental plot situated on the Hoover farm east of Petosky. Here, under the direction of Dr. B. B. Robinson, of the Division of Cotton and Other Fiber Crops and Diseases, a corn patch which had been observed to be infested with milkweed the previous season had been appropriately fertilized and cultivated in connection with yield studies. As a consequence the area was covered with a dense stand of milkweed. In the course of a fairly rapid sampling of fruits, over 38 not merely different but very distinctive pod types were obtained. Furthermore, in an area of approximately one-half acre in western Washtenaw County, the 12 "Toma" types described in this paper were collected. It appears quite certain, therefore, that these distinctive pods are not mere environmental variations but, rather, genetic entities.

Further evidence supporting this interpretation is to be found in the results of greenhouse experiments of a preliminary nature made at the University of Michigan botanical gardens early in 1944. Here, plants of known clonal origin and pod type were forced into flower and hand-pollinated with pollen from plants also of known clonal origin and pod type. As might be expected, it was found that the type of pod developed was like that formed the previous growing season so far as shape and type of ornamentation were concerned. Seeds resulting from these crosses have been germinated and eventually close inbreeding will be possible. It might be remarked here that *Asclepias syriaca* for several reasons is not well suited for genetical studies. Complete self-incompatibility appears to be the general condition, at least so far as the Michigan material is concerned. Furthermore, hand-pollination is an arduous task and the number of flowers which an individual can pollinate in a day is decidedly limited. Lastly, at least 2 years must elapse [5] from the time the seeds are planted until fruits are produced. Gerhardt [5], however, reports that five seedlings

[5] GERHARDT, F. PROPAGATION AND FOOD TRANSLOCATION IN THE COMMON MILKWEED. Jour. Agr. Res. 39: 837–851, illus. 1929.

in a plot 100 feet square came into bloom the first year, indicating their fundamentally annual nature. No seedlings of this type have thus far been found in the present study.

Correlated with differences in pod types, there are also differences in floss characteristics. Hence, selection of plants bearing pods with favorable floss qualities can be made the starting point for commercial clones, which, when interplanted with other, mutually compatible, desirable clones will provide the basis for improved milkweed culture.

SUMMARY

In the present paper 49 distinct types of pods of the common milkweed (*Asclepias syriaca*) are described and illustrated. These were collected from 12 different counties in the Lower Peninsula of Michigan. They by no means exhaust the number of types which are to be found in this region. The presence of so many different types within a very limited area suggests that they represent genetic entities rather than environmental variations.

INSECTICIDAL PROPERTIES OF THE INDIGOBUSH (AMORPHA FRUTICOSA)[1]

By CHARLES H. BRETT[2]
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INTRODUCTION

During the past few years a shortage of rotenone has resulted in considerable effort being made to develop supplies of this material in the Americas. Plantings of *Lonchocarpus* have been vastly increased in South America, and many plants have been investigated in the search for new sources. In 1937, Moore (*12*) [3] reported, on the basis of positive Durham tests, that rotenone was present in the roots, stems, bark, and seeds of cat willow (indigobush) plants from Nebraska. Since this plant is abundant throughout the Mississippi Valley, Featherly [4] in 1942 suggested that it might be a worth-while source of rotenone during the war emergency. Investigation of this possibility was undertaken by the Oklahoma Agricultural Experiment Station.

Biological analyses of samples of the fruit from numbered plants growing in the horticultural nursery, with larvae of the yellow-fever mosquito (*Aedes aegypti* (L.)) as the test insect, were made to determine the variation in toxic content. Methods for extracting the toxic agent and using it experimentally were also studied. Twenty-nine species of insects were tested in the laboratory to determine the insecticidal value of *Amorpha fruticosa*. Some experiments were also conducted on its repellent characteristics.

THE PLANT

Amorpha fruticosa L. is variously known as the indigobush, cat willow, or river locust, and belongs to the family Leguminosae. It grows as a shrub 3 to 8 feet tall (fig. 1). The leaves are odd-pinnate with 9

[1] Received for publication December 16, 1944.

[2] While conducting this investigation the writer received very valuable assistance and suggestions from the following persons: Drs. D. E. Howell, H. I. Featherly, Frank B. Cross, F. A. Fenton, Geo. A. Dean, E. E. Harnden, and Prof. G. A. Bieberdorf.

[3] Numbers in parentheses refer to Literature Cited, p. 96.

[4] Dr. H. I. Featherly, of the Department of Botany and Plant Pathology, Oklahoma Agricultural and Mechanical College, holds patent pending serial number 459577, series 1935, covering the insecticidal, acricidal, piscicidal, vermifuge, animal-dip, and animal-wash value of compounds derived from plants belonging to the genus *Amorpha*, family Leguminosae.

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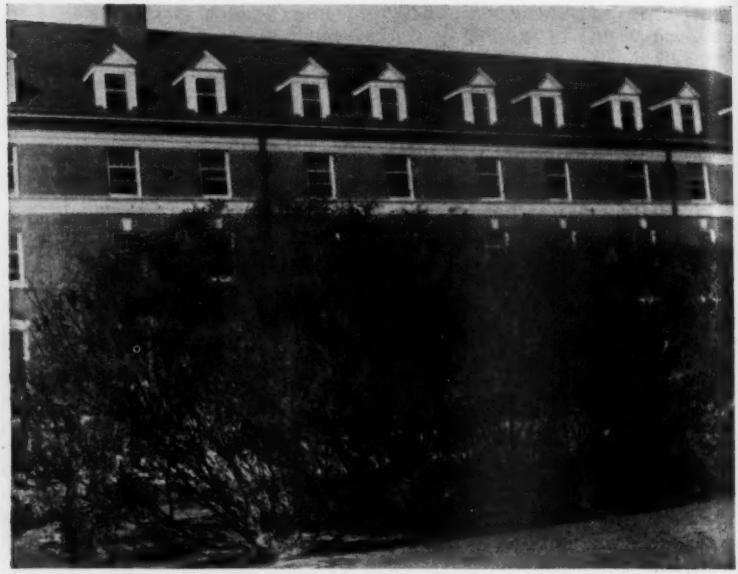

FIGURE 1.—*Amorpha fruticosa* plants growing as ornamentals on the Oklahoma Agricultural and Mechanical College campus.

to 25 oblong to broadly elliptical leaflets. Purplish flowers are borne on a cluster of spikelike terminal racemes on new wood. Pods are one-seeded, indehiscent, curved, and more or less covered with glands or resinous blisters (fig. 4). They measure 6 to 10 mm. in length. The flowers appear in May and June. The fruit matures in the fall and remains on the plant throughout most of the winter (fig. 2).

The plant is native throughout central North America from Pennsylvania to the Rocky Mountains and from Manitoba to Mexico. While it grows naturally along streams, ravines, and in moist places, it has been used in recent years as an ornamental, showing adaptability to a wide range of habitats.

Plants are now being grown by the Department of Horticulture at the Oklahoma station to study methods of propagation and harvesting and to determine the genetics of the toxic or repellent agent. The pods, which contain one seed each, are planted with a garden drill at the rate of 8 to 10 pounds per acre in rows 3 feet apart. The best planting date for this area appears to be from about April 10 to 20. Young plants can be seen coming through the soil in approximately 10 days. It has been found advisable to cultivate as soon as the rows are visible to prevent an overgrowth of crabgrass and other weeds.

During the first year plants attain an average height of 10 to 15 inches. A small amount of fruit usually is produced the second year but the quantity is negligible. Third-year plants reach a height of 36 to 40 inches and develop an abundance of seed. At the present time no method for harvesting has been worked out; pods obtained for experimental purposes are stripped from plants by hand.

FIGURE 2.—Terminal portion of a branch of *Amorpha fruticosa*, showing clusters of fruit.

SOME INSECTS ASSOCIATED WITH THE INDIGOBUSH

Seeds of the indigobush may be heavily infested by a small bruchid, *Acanthoscelides floridae* (Horn).[5] Larvae develop in the beans and consume most of their content. The weevil overwinters in the larval stage, pupating and emerging in about 2 weeks when the pods are brought into a warm room. Three species of hymenopterous parasites were reared from the bruchid, namely, *Horismenus missouriensis* (Ashm.), *Eupelmus cyaniceps amicus* (Gir.), and *Catolaccus* spp.[6] The first named was extremely prevalent.

During the summer a gall (fig. 3) develops in the terminals stems,

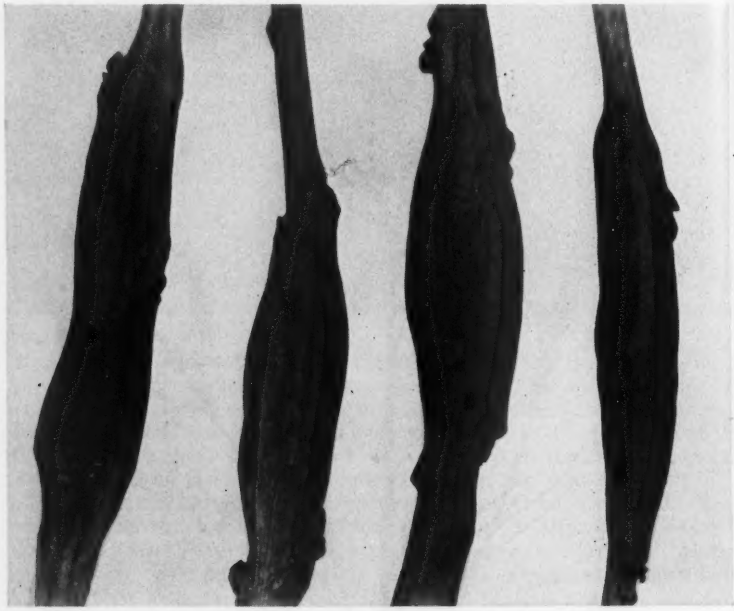

FIGURE 3.—Galls caused by the cat willow moth, *Walshia amorphella*.

caused by the larva of a moth, *Walshia amorphella* (Clem.). A braconid parasite, *Microgaster ecdytolophae* Mues.,[7] and an ichneumonid parasite, *Pristomerus euryptychiae* Ashm.,[8] were reared from these larvae.

[5] Identified by H. S. Barber, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture.

[6] Identified by A. B. Gahan, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture.

[7] Identified by C. F. W. Muesebeck, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture.

[8] Identified by H. K. Townes, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture.

PREPARATION OF EXTRACTS

All of the material used in these studies was extracted with a Soxhlet apparatus from the mature fruit. In the first preparations, fruits were ground with a Wiley mill and acetone or chloroform was used as the solvent. This resulted in a filtrate which contained so much waxy material that it was almost impossible to use on dusts. The most satisfactory method of extraction was found in the following procedure:

Unground fruits are carefully weighed and about one-fourth their weight of decolorizing carbon is thoroughly mixed with them. This preparation is then placed in an extractor thimble and set in the Sohxlet apparatus. Acetone is used as the solvent with the electric heating unit operating at the lowest boiling temperature. Extraction is continued for 24 hours. At the end of that time the filtrate is placed in a refrigerator at a temperature of about 40° F. The waxes solidify within 24 hours, and can then be removed with a fine filter paper. The final filtrate is "standardized" by bringing it to a volume in cubic centimeters equal to the original weight of the pods in grams. This filtrate has the appearance of weak tea and can be placed successfully on dusts. The extract slowly changes to a red color. High temperatures accelerate the change. If the filtrate is dried and heated for a period of time it will show an almost blood-red color when redissolved in acetone. Toxicity is slightly reduced by this procedure.

Samples of extract stored under room conditions and tested for toxicity at regular intervals during 6 months showed no apparent loss in strength. Pods stored in fruit jars at room temperature for 2 years yielded an extract of high toxicity.

SOME CHEMICAL PROPERTIES OF THE EXTRACT

When the acetone solvent is evaporated from *Amorpha fruticosa* extract, three physically different substances are found in the residue. One is an oil-soluble, viscous, cream-colored material which thickens and becomes waxlike. A second oil-soluble fraction is a clear oil which separates out on top of the residue, and the third is a brownish, gummy material which collects at the bottom. This gum is not soluble with the other components or with petroleum oils and does not contain the repellent agent. The residue has a sweet pleasant odor which reminds one of spices if it is not sensed too strongly.

One of the most interesting aspects of the chemistry of *Amorpha* extract is its positive reaction to tests considered specific for the rotenoids, the most significant of which is the Durham test as reported by Gimlette (*9*). In 1939 Le Geyt Worsley (*11*) defined rotenoids as those substances which answer, collectively, to Durham's test. Roark (*13*) states that the term "rotenoid" was first used by the American chemist Dr. Hyym E. Buc in an application for a United States patent filed March 12, 1931. It was again used by L. A. Mikeska in an application for a United States patent filed October 29, 1932. In both instances the term was used in respect to insecticidal action. Roark believes it unwise to define "rotenoid" in terms of the Durham color test since better color tests have been developed for quantitative purposes.

Of the several chemicals, including rotenone, which are in the

rotenoid group, two types or classes are usually considered. These are a nonphenol group which includes rotenone, deguelin, and tephrosin with their respective derivatives, and a phenol group which includes toxicarol, sumatrol, and malaccol with their derivatives. All of these give the red Goodhue (*10*) color. The phenol group, however, will produce a green or green-brown color with ferric chloride. Cahn, Phipers, and Boam (*5*) described such a color for the determination of toxicarol. *Amorpha fruticosa* acetone extract was found to give excellent reactions to the Durham, Goodhue, and ferric chloride tests. Attempts to correlate these tests with toxicity showed no significant relationship.

An alternating current model Fisher electrophotometer was used in evaluating the color values, and third or fourth instar yellow-fever mosquito larvae were used as test insects for evaluating toxicity. It was quite apparent in the results obtained that the agent responsible for a reaction to the Goodhue test was not the same that produces a reaction to the ferric chloride test.

At the request of Dr. H. I. Featherly, the Bureau of Entomology and Plant Quarantine examined samples of *Amorpha fruticosa* beans from several localities. All were positive to Durham's test but no rotenone could be isolated. Acree, Jacobson, and Haller (*2*), who conducted the tests, reported that fractionation of chloroform extractives of seed collected at Vermillion, S. Dak., yielded a slightly hygroscopic glycoside that melted at 151°–151.5° C. and gave a positive Durham test. The name "amorphin" was suggested and the formula $C_{33}H_{40}O_{16}$ was assigned. Amorphin was further found to give a positive orcinol test and a negative phenol test. It will not reduce Fehling's solution until after acid hydrolysis. Warmed with concentrated hydrochloric acid it dissolves to form a product which melts at 191°–192° C. This compound, an aglycon of amorphin, is designated as "amorphigenin" with the formula $C_{22}H_{22}O_7$. It also gives a positive reaction to the Durham test. The acid filtrate obtained in the hydrolysis of amorphin readily reduced Fehling's solution but the sugar portion of the molecule could not be isolated.

Two compounds which reacted to the Durham tests were found in the extractive of *Amorpha fruticosa* by Beliaev (*4*). One was soluble in ether; both were soluble in chloroform.

The toxic or repellent agent in the indigobush has yet to be identified. Apparently it does not belong to the rotenoid group, but factors in the extracts which give a positive reaction to tests heretofore considered specific for the rotenoids have made this a very confusing problem. For the sake of simplicity in referring to the insecticidal substance or substances occurring in *Amorpha fruticosa*, the term "amorpha," after the generic name of the plant, will henceforth be used.

BIOLOGICAL ANALYSES TO DETERMINE THE TOXICITY OF INDIVIDUAL PLANTS

Fruit was collected from numbered plants growing in the horticultural nursery. A sample from each plant was analyzed biologically. Seeds of some of the most and least toxic fruits have been planted in

the nursery, and it is planned to analyze the fruit of this progeny when it is available and to determine any variation in parent stock from year to year in a study of the genetics of the toxic principle.

REARING OF TEST INSECTS

A population of the yellow-fever mosquito (*Aedes aegypti*) was maintained for use in the biological analysis of numbered *Amorpha fruticosa* plants. Adult insects were held in a large screen cage lined with fine rayon curtain material. Male mosquitoes were fed moistened raisins. Guinea pigs supplied a source of blood for the females. Eggs were deposited on paper toweling partly covered with distilled water in a bowl, and were transferred each week to gallon crocks containing water. Powdered pablum and fecal pellets from sheep or goats served as larval food. Pupae were placed in beakers of water in the mosquito cage.

TOXICOLOGICAL PROCEDURE

Four dilutions of standardized amorpha extract in water (1 to 100, 1 to 200, 1 to 400, and 1 to 800) were used as test solutions. Ten cc. of each was placed in 25-cc. Stender dishes and the series replicated twice. Check tests were set up in the same manner, using a 1-percent solution of pure rotenone in acetone.

To avoid variation in vigor of the larvae, all used in any one test were taken from the same larval stock. Ten larvae were transferred from the rearing culture to each prepared Stender dish. Trays of a size to accommodate the eight Stender dishes in a single test were used in placing them in a constant temperature compartment held at 90° F., since Gersdorff (*8*) has shown that temperature changes the resistance of an insect to toxins,

To increase the significance of the interpretation regarding toxicity, a scoring method was adopted based on the theory that toxic action would be in proportion to time and concentration. The number of larvae dead in each Stender dish was determined at intervals of 1, 2, 4, 8, 12, and 24 hours. The number of larvae dead after a given number of hours was multiplied by that number, and the number still alive at the end of 24 hours was multiplied by 48. These products were totaled and this figure was designated as a score. For example, if 10 insects died in 1 hour the score would be 10, and if 10 more insects died the second hour the score would be 20. Ten dead insects at the end of 3 hours would give a score of 30, etc. The final score for this example would be 10+20+30, or 60. Assuming the score in the rotenone control (*CS*) as equaling 100, a rotenone ratio was obtained by dividing the score of the test sample into that of the rotenone control and multiplying by 100. Letting *RR* equal the rotenone ratio, *TS* the test score, and *CS* the check score, an index to the toxicity of a given extract can be expressed by the formula $RR=\frac{CS}{TS}\times 100$. Six extracts were tested against 1 control in each operation. This was found to be the maximum number that could be handled efficiently at one time.

VARIATION OF TOXICITY IN DIFFERENT PLANTS

Of the 125 numbered plants in the nursery, 33 were either dead or yielded such a small amount of seed that it could not be analyzed. The plants ranged from 5 to 8 feet tall, and varied in yield from 0.5 gm. up to 254.6 gm. of fruit per plant.

The difference in toxicity between the fruit samples tested, gram per gram, is shown in the following tabulation.

Rotenone ratio (*RR*):[1]	*Number of plant samples tested*
25–49	6
50–99	33
100–199	37
200–399	12
400–500	4

[1] Checks made up from a 1-percent solution of pure rotenone in acetone always equal 100.

The percentage toxicity to *Aedes aegypti* among the samples ranged from 52 in the 25–50 *RR* group to 100 in the 400–500 group. Therefore, it appears that in these tests amorpha was somewhat more toxic to yellow-fever mosquito larvae than was 1-percent pure rotenone. Toxicarol was found to have a rotenone ratio of about 32 and caused a 61-percent mortality. Since some acetone blanks showed an *RR* of 38, the toxicarol and those plants with an *RR* of 50 or below were not considered as being significantly toxic.

DISTRIBUTION OF THE TOXIC AGENT IN THE PODS

When fruit samples from the least and the most toxic groups were examined under a binocular microscope it could readily be seen that the more toxic fruit had larger and more abundant pustules on the coat than the less toxic ones (fig. 4, *A* and *B*). The more toxic samples also appeared to be somewhat darker and gave a stronger amorpha odor. No doubt several factors are important in determining the amount of toxin per gram of fruit. Some of these may be the size of the pod, its weight per volume (which would vary according to degree of weevil injury), and the actual concentration of toxin in the fluid of the blisters.

When probed with a needle under the binocular, pustules on the pod were seen to exude a reddish-brown, viscous fluid. That this material contained most of the amorpha was shown by the following test. Pods were carefully shelled by hand. Seeds and coats were extracted separately and their extracts standardized. To mosquito larvae used as in the above-described procedure, the coats were found to be far more toxic than the seeds. There appeared to be some toxin in the seeds, but this could have been due mostly to the presence of a sticky material on the surface. Both extracts reacted to the Goodhue and ferric chloride tests but a deeper color was obtained from the coats. Since most waxes are present in the seed, the desirability of extracting unground fruit can readily be seen even though grinding may slightly increase the amount of toxin extracted.

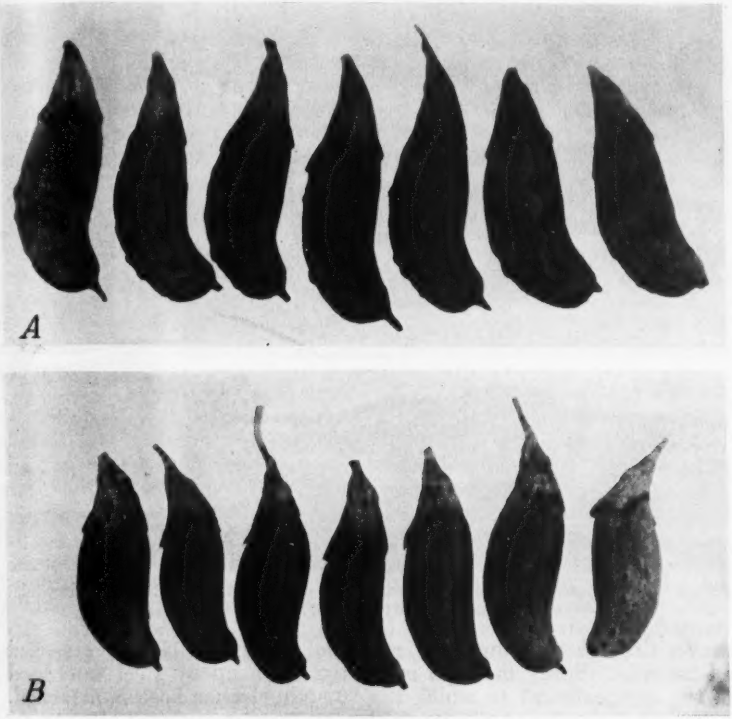

FIGURE 4.—*A*, Sample of the more toxic fruit of *Amorpha fruticosa*, showing many large pustules on the pod; *B*, sample of the less toxic fruit showing only a few small pustules on the pod. Actual length about 6 to 10 mm.

INSECTICIDAL TESTS

METHODS OF PREPARING AND TESTING SPRAYS

Most sprays were in the form of aqueous emulsions, which were satisfactorily prepared by adding standardized acetone extracts to distilled water. A preparation containing 10 cc. of extract in 90 cc. of water was considered a 10-percent concentration. The milky-white emulsion was applied generally at 5 or 10 percent.

Two types of apparatus were used in obtaining uniformly complete coverage with spray material. Figure 5, *A*, shows a settling-mist apparatus patterned after the plan of Hoskins (*6*) but constructed of sheet iron rather than glass. Two cubic centimeters is the effective volume of spray, since more than this results in an overflow of the mist if it is all applied at one time. Figure 5, *B*, shows a spray tunnel of a type similar to that used by Eagleson (*6*). A De Vilbiss atomizer operated at a constant pressure of 12.5 pounds is used with both pieces of equipment. Insects are held in cylindrical screen cages which are revolved in the tunnel. A continuous current of air is

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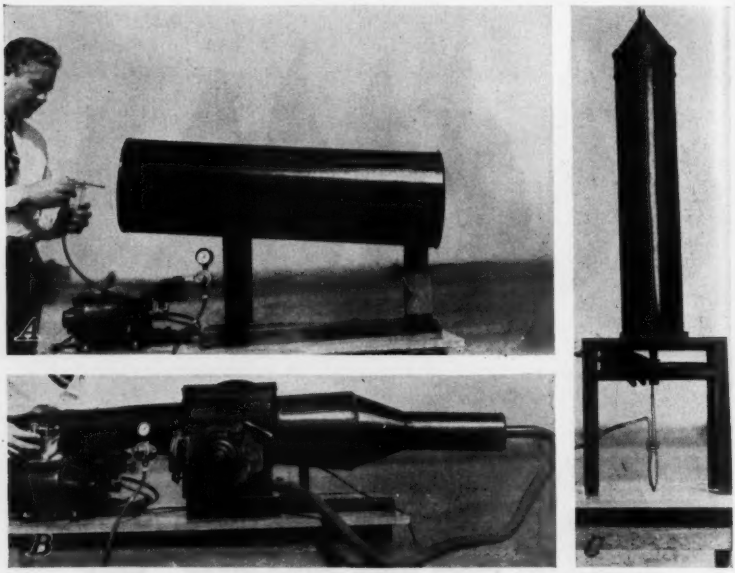

FIGURE 5.—Laboratory apparatus for testing dusts and sprays: *A*, settling-mist apparatus; *B*, spray tunnel; *C*, dust tower.

drawn through the tunnel by means of a vacuum cleaner attached at the side. Spray material is mostly taken up by steel wool held in the compartment to which the vacuum-cleaner hose is attached.

For most significant results the insects were transferred after treatment to lantern globes in which they were confined with food material. In some tests the globes were held in a constant-temperature recovery cabinet.

METHODS OF PREPARING AND TESTING DUSTS

One of the greatest difficulties in preparing dusts from amorpha extract arises from its tendency to cause waxiness or gumminess. A maximum of superfluous waxes was removed by the extraction method described, but there was still some lumpiness with certain dusts. Finely ground walnut-shell flour proved to be the most satisfactory of those tested, probably because of its absorbtive qualities.

"Standardized" dust was prepared by pouring acetone amorpha extract into a container holding walnut-shell flour, the number of cubic centimeters of extract being equal to the number of grams of dust used. This was stirred until most of the acetone had evaporated and then allowed to stand until completely dry. Such a standardized dust could be diluted to any desired extent with more flour, or it could be more greatly concentrated by adding acetone extract. Preparations made by grinding whole pods contained so much wax that they were difficult to use.

Two methods were followed in applying dusts. A tower (fig. 5, *c*) similar to that described by Waters (*6*) was used in treating leaves

upon which such small arthropods as aphids and red spiders were feeding. Dusts were placed in a cylinder which has a tapered glass tube inlet reaching close to the surface of the dust. The glass tube, which as an outlet, is pushed into the hole of the rubber stopper until it is just flush with its inner surface. This tube is long enough to extend through the central cylinder in the revolving table and is tapered at its outlet. Air for dusting is supplied by the motor compressor at 12.5 pounds' pressure. By placing a glass plate of known weight and area on the revolving-leaf table and reweighing it after each test, the volume of dust applied can be accurately determined.

A technique which will be referred to as the fruit jar-lantern globe method was used extensively in laboratory tests in which dusts were employed. The insects to be treated are placed in half-gallon mason jars and caged with a Kerr-type jar lid using a screen in place of the central disk. The same unit for dusting is used as was described with the dust tower. It consists of a cylinder with two glass tubes and is attached to the motor compressor. The cylinder containing dust is carefully weighed before and after dusting to determine the amount applied. When a jar is ready to be dusted the screen lid is removed and the jar is tilted slightly with the open end down. A single puff of dust is administered; this usually weighs from 50 to 150 mg. depending upon the type of dust. The jar is closed and turned for a minute or more to allow for settling. It is then opened and inverted into the upper end of a lantern globe. The insects move into the lantern globe which contains food plants. At regular intervals the number of dead insects in each globe is determined by picking them out with a pair of forceps. By this method it is possible to test the effect of dust on a large number of active insects in a short time.

RESULTS OF TESTS

Each individual test was repeated once or twice with two or three replicates per test. A total of 200 or more insects was usually used with each type of treatment. In this paper the average results from all tests are given, with the effective control calculated from Abbott's formula (*1*).

Amorpha acts both as a stomach and a contact poison. Laboratory tests with sprays or dusts were made on 29 species of common insect pests. The data, most of which are given in table.1, did not show amorpha to be highly toxic, although standard amorpha dust gave a control of 81 percent or better for the chinch bug, cotton aphid, pea aphid, bean leaf beetle, spotted cucumber beetle, and mosquito larvae. It was not very effective as a spray for the Colorado potato beetle, although all were killed when dipped in a 10-percent solution. The percentage of control by dusting was fair (32 percent–67 percent) for a species of stink bug, the tarnished plant bug, squash bug, potato leafhopper, tent caterpillar, two species of blister beetles, and the confused flour beetle. There was a 16-percent control of boll weevils and 7.2 percent control of cotton flea hoppers. Control was nil for ailanthus moth larvae, alfalfa caterpillar, wooly bear caterpillar, cabbage loopers, two species of grasshoppers, chrysanthemum aphids, mealybugs, houseflies, red spiders, chicken mites, and dog fleas.

TABLE 1.—*Effect of amorpha on certain insects and mites in laboratory tests, Stillwater, Okla., 1943–44*

Insect used in test	Stage	Type of treatment	Strength	Time from treatment until residing	Average dead in treated lot	Extent of effective control
				Hours	*Percent*	*Percent*
Cotton flea hopper (*Psallus seriatus*).	Nymphs, adults.	Dust	Standard	4	42.5	7.2
Chinch bug (*Blissus leucopterus*).	do	do	do	4	97	97
Stink bug (*Thyanta custator*)	Adults	do	do	18	66	49
Tarnished plant bug (*Lygus pratensis oblineatus*).	do	do	do	20	37	32
		Aqueous spray	10 percent	4–8	62	13
Squash bug (*Anasa tristis*)	Nymphs, adults	do	Standard	48	38.7	28
Potato leafhopper (*Empoasca fabae*).	Adults	do	do	3	67.3	31.8
Cotton aphid (*Aphis gossypii*)	Numphs, adults	Dust	Standard, 0.28 mg.	24	49	
		do	Standard, 0.85 mg.	24	93	89
		do	Standard, 4.1–5.4 mg.	24	100	
Pea aphid (*Macrosiphum pisi*).[1]	do	do	½ standard	48	97	81
Chrysanthemum aphid (*Macrosiphum sanborni*).	do	Acetone spray	Standard	48	100	
		Dust	do	48	0	
Mealybugs (*Pseudoccus spp.*)	do	do	do	72	0	0
Grasshoppers (*Melanoplus spp.*).	Adults	Extract residue on lettuce leaves.	do	96	0	0
Housefly (*Musca domestica*)	do	Dust	do	24	0	0
		Aqueous spray	5 percent, 10 percent.	10		0
Ailanthus moth (*Attera aurea*).	Larvae	Extract residue on ailanthus leaves.	Residue	24		0
Eastern tent caterpillar (*Malacosoma americana*).[1]	do	Extract residue on sand plum leaves.	do	24	(2)	(2)
Cabbage looper (*Plusia brassicae*).[1]	do	Dust	Standard	48		0
Banded woolly bear (*Isia isabella*).[1]	do	do	do	48		0
Alfalfa caterpillar (*Colias eurytheme*).	do	do	do	36	5	0
Colorado potato beetle (*Leptinotarsa decemlineata*).	do	Aqueous spray	10 percent, 2 cc.	24	16	16
		do	10 percent, 4 cc.	24	27.5	27.5
		do	10 percent, 6 cc.	24	43	43
		Dipped	10 percent	16	100	100
		Extract residue on potato leaves	Residue	48	49	46.9
Confused flour beetle (*Tribolium confusum*).	Adults	Impregnated flour.	Series of different dilutions.	192	67	67
Blister beetles (*Macrobasis unicolor* and *Epicauta lemniscata*).	do	Dust	Standard	36	69	65
		Extract residue on lettuce leaves	Residue	48	45	55
Boll weevil (*Anthonomus grandis*).	do	Dust	Standard	24	25.8	16
Bean leaf beetle (*Ceratoma trifurcata*).	do	do	do	48	87	86
Spotted cucumber beetle (*Diabrotica duodecimpunctata*).[1]	do	do	do	48	92	91.8
Chicken mite (*Dermanyssus gallinae*).	Nymphs, adults	do	do	72		0
Red spider (*Tetranychus telarius*).	do	do	do	24	0	0

[1] Tests made by D. E. Howell.
[2] High percentage.

The comparative effectiveness of amorpha dust and other insecticides is shown in table 2. Only in the case of the chinch bug was the

TABLE 2.—*A comparison of control obtained with amorpha and other insecticides*

Insect used in test	Extent of control with—					
	Standard amorpha dust	325-mesh sulfur dust	3-percent DDT dust	5-percent derris dust	1-percent nicotine dust	1-percent pyrocide
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Cotton flea hopper	7.2	87.9	100			
Chinch bug	97	100	49	100	59	
Tarnished plant bug	32	0	100			67
Squash bug	28		77			70
Potato leafhopper	31.8	95				
Cotton aphid	89			100	100	
Pea aphid	81			100		
Chrysanthemum aphid	0			90		
Alfalfa caterpillar	0		100			

control approximately the same. Sulfur dust (325-mesh, undiluted) was superior to amorpha as a control for the cotton flea hopper and the potato leafhopper. Three-percent DDT dust gave better control than amorpha for the cotton flea hopper, the tarnished plant bug, the squash bug, and the alfalfa caterpillar. A 5-percent derris dust was also superior to amorpha as a killing agent against the chinch bug, the cotton aphid, the pea aphid, and the chrysanthemum aphid. One-percent nicotine dust was more effective than amorpha for the control of the cotton aphid, and pyrocide was better for the tarnished plant bug and the squash bug.

Several tests of the insecticidal value of amorpha have been made elsewhere. Robert T. Wallace at the New Jersey Agricultural Experiment Station (unpublished correspondence), injected aqueous extracts into the blood stream of the American cockroach (*Periplaneta americana* (L.) and found it to be about one-tenth as toxic as *Derris* which contained 4.7 percent rotenone.

E. W. Laake, of the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture, reported (unpublished correspondence) that tests made by W. T. Hunt at Dallas, Tex., on the short-nosed cattle louse (*Haematopinus eurysternus* (Nitz.)), in which amorpha dust at double its standardized strength was used, resulted in a mortality of approximately 50 percent of the motile stages in 24 hours.

Featherly and Harmon (7) found that a 10-percent aqueous amorpha emulsion killed all cattle grubs on animals treated. With soap as a wetting agent or when less than a 10-percent emulsion was used, toxicity was reduced.

Standardized dust rubbed into the hair of dogs caused over 70 percent of the fleas (*Ctenocephalides canis* (Curtis)) to drop off within 3 hours. No significant toxic effect occurred.

REPELLENCY

While amorpha was being tested for its insecticidal value, observations indicated that it was repellent to certain insects. Chinch bugs were greatly activated by it and swarmed about the inside of the

lantern globes in an attempt to escape. This did not occur with other treatments than amorpha. Chrysanthemum aphids did not leave their host plants but showed distinct irritability in the form of a greatly increased jumpinglike body movement. Lettuce leaves which had been treated with amorpha were avoided by grasshoppers and blister beetles for a period of nearly 24 hours. Tent caterpillars fed very lightly on sand plum leaves coated with amorpha, and ailanthus moth larvae avoided treated leaves of their host plant entirely. Adults of the confused flour beetle tended to leave flour impregnated with amorpha and collect on the underside of the Stender dish lid. After a period of 48 hours or more they would enter the flour to a certain extent, but the whole population never entirely covered itself as in the untreated checks. Nearly all dog fleas left their host within 3 to 6 hours after amorpha dust had been applied.

Because of these observations it was decided to make a few tests to determine the value of amorpha as a repellent. Accordingly, a fly bait was made of watermelon, peaches, sour milk, and sugar, all mashed together. The mixture was allowed to stand for a few days. Heavy paper was then cut into four pieces, each about 1.5 feet square, and the bait was painted on the center of two of the pieces over a square-foot area. The bait was allowed to dry until it adhered firmly to the paper. One baited and one unbaited paper were sprayed with 2 cc. of a standardized amorpha acetone solution. A few minutes were allowed for the acetone to evaporate. The papers were then taken to a dairy barn and placed on the floor by a pile of ensilage which was swarming with houseflies. Originally it was thought that counts could be made of the number of insects on each paper at regular intervals, but at the end of 10 minutes the untreated bait was black with flies. The number of flies on the unbaited and untreated paper ranged from 3 or 4 to over 20. The unbaited and treated paper was usually free of flies; from time to time 1 or 2 would alight but they soon left. The flies on treated bait averaged about 2 dozen at a time and these were found on lumps of material which could have absorbed the amorpha. It was interesting to note that when the insects were stirred into flight the swarm would very shortly focus and settle on the untreated bait, apportioning themselves quickly in about the ratio described above.

This test was repeated and elaborated by using oil sprays containing amorpha. It was found that the gum portion of the residue from acetone extracts did not contain the repellent agent but that it was present in the waxes and oils which were soluble in petroleum oils. Base fly spray oil containing the residue from 10 cc. of acetone amorpha extract dissolved in 20 cc. of oil was used in the tests. Repellency was apparently undiminished for a period of 10 to 12 hours. After that it began to drop off and the spray was not appreciably effective in 24 hours.

A number of spray tests with amorpha in oil were made on cattle. Some of the results obtained are shown in table 3. The bull in test 1 and the calves in test 2 were confined in the barn. Ten cc. of amorpha oil spray was applied to one side of the bull, the unsprayed side serving as a control. Approximately 5 cc. per whole animal was sprayed on the calves. Most of the flies were houseflies. The cows in

test 3 were held in a corral except for short feeding periods in the barn. They were sprayed at the rate of 10 cc. per whole cow but flies were counted only on the left side of each animal while it was exposed to the sun except for the counts made at the end of 8 hours, at which time the animals were feeding in the barn. More than two-thirds of the flies on these animals were horn flies (*Haemotobia irritans* (L.)). While the cows were in the barn, counts increased somewhat as a result of the presence of houseflies.

These tests, while not conclusive, show amorpha to be unusually effective in maintaining its repellency for more than 12 hours.

TABLE 3.—*Average number of flies on animals sprayed with amorpha as compared with number on checks, Stillwater, Okla., 1944*

Hours after treatment	Number of flies on animals in test—					
	1[1]		2[1]		3[2]	
	Check; ½ of bull unsprayed	½ of bull sprayed	Check; 4 calves unsprayed	4 calves sprayed	Check; 5 cows unsprayed	6 cows sprayed
4	65	7				
6			81	10	31.8	6.6
8	55	12	80	13	55	12
12	58	7	74	29	38	18
30	62	54	67.7	33.7	41.8	35.3

[1] Mostly houseflies.
[2] Approximately two-thirds horn flies, the rest houseflies.

TOXICITY TO MAMMALS

The residue from acetone amorpha extract on human skin for a period of 8 hours showed no injurious effect. No irritation or reddening was noted. Using the preparation as a spray on cattle and as a dust on dogs did not produce toxic symptoms.

A capsule containing 3 grains (0.2 gm.) of residue, an amount which would be obtained from 4 gm. of *Amorpha fruticosa* pods, was administered to a guinea pig. No effect could be seen at the end of 6 hours, but the animal died within 18 hours. An examination revealed extensive disintegration of the stomach and a mucous formation in the duodenum.

Guinea pigs which had been without food for 96 hours refused to eat head lettuce leaves treated with amorpha even when they had no alternative food. They were confined with treated leaves for 48 hours of the 96-hour period.

SUMMARY

A new insecticidal plant has been found in the indigobush (*Amorpha fruticosa* L.) Studies were originally started on this plant because color reaction indicative of the rotenoid group had been obtained from extracts of the seeds, stems, roots, and leaves. No rotenone has been isolated, but a glycoside which reacts to the rotenoid tests was discovered by the Bureau of Entomology and Plant Quarantine of the U. S. D. A.

The toxic principle has not been determined. The term "amorpha" has been used to designate it. Most of the amorpha occurs in resinous

pustules on the pods. The size and abundance of these pustules varies greatly.

Seed from individually identified plants has been analyzed biologically as a guide to selection or breeding of plants for high yield of amorpha.

A few insects which commonly inhabit the indigobush have been identified and briefly studied. The bruchid *Acanthoscelides floridae* was found to feed on seeds sufficiently to be considered a serious pest. It is parasitized by certain species of wasps.

Laboratory and field tests with amorpha in dust and sprays have been made on 29 species of insects or mites. It acts both as a stomach and contact poison. Amorpha extract obtained up to the present time has not included any highly toxic material; however, it has been effective in the control of a few insects.

One of the most interesting characteristics of amorpha extract is its repellency, which persists for more than 12 hours.

Little is known regarding the toxicity of amorpha to mammals. However, it appears that it would be poisonous if taken internally. No effect has been noted on the skin.

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ENVIRONMENTAL MODIFICATION OF FIBER PROPERTIES AS A SOURCE OF ERROR IN COTTON EXPERIMENTS [1]

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INTRODUCTION

It is recognized that environmental conditions during the period of fiber development influence the physical properties of cotton fiber. In certain areas of the Cotton Belt soil and climatic conditions may be favorable for producing cotton of superior quality, whereas in other areas less favorable conditions may limit production to short-stapled types of lower commercial value. Environmental changes, however, may occur frequently during the growing season and from year to year. The effects of varying environment are an unavoidable hazard in the commercial production of cotton, but in cotton-improvement investigations environment introduces bias and is a disturbing influence in breeding for fiber quality. Variability of certain fiber properties as influenced by environment is discussed in this paper.

Numerous workers have studied the variability of cotton fibers on individual seeds, from different seeds within locks, from different bolls on the same plant, and from plants at different locations in the field. Fluctuating variations in cotton due to seasonal or soil conditions are recognized, but conflicting evidence indicates that locational factors strongly influenced the results. Nelson and Ware (*11*) [3] reported that staple length was not affected by the nitrogen-phosphorus-potassium levels, but they found seasonal variation in fiber length from 30/32 to 34/32 of an inch in 4 years of trial. Moore and Rankin (*9*) found that additional potash applied to fields subject to "rust" increased fiber length and strength and reduced the percentage of thin-walled fibers. Reynolds and Killough (*15*) reported that

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[3] Italic numbers in parentheses refer to Literature Cited, p. 110.

length of fiber was positively correlated with the amount of rainfall during the period of boll development in 2 of 3 years of experiment at College Station, Tex., but that no correlation was apparent between rainfall and length of fiber during 1 year of work at Troup, Tex. Pope (*12*), in Arkansas, and Neely (*10*), in Mississippi, concluded that staple length was basically controlled by genetic factors but was significantly modified by soil and seasonal conditions.

From studies of Pima cotton under irrigation in Arizona, Kearney and Harrison (*7*) concluded that fiber from bolls borne on the lower fruiting branches was shorter than that from bolls situated higher on the plant. Porter (*13*), at Greenville, Tex., found that the mean length of lint fluctuated from season to season but that length tended to increase from early- to late-season bolls. From field tests in South Carolina, Armstrong and Bennett (*1*) concluded that position of boll on the plant did not seem of great importance in determining length of lint, but they found a distinct tendency for shorter lint to be produced in late-season bolls.

Variations in uniformity, fineness, and strength are not discussed extensively in the literature, as instruments for rapid measurement of these properties have been developed only recently. King (*8*) stated that fiber produced in areas where the plants suffered from water stress was usually weaker, less abundant, shorter, and more uneven in length than that developed under favorable conditions. Pope (*12*), in seasonal and locational comparisons in Arkansas, found that relatively small environmental differences significantly affected strength of fiber. Hancock (*4*), in varietal studies in Tennessee, concluded that length, fineness, and strength were independent genetically, but that under certain environments length and fineness were positively correlated and length and strength were negatively correlated.

MATERIALS AND METHODS

Fiber used in this study was grown in 1941 and 1942 at six locations in the Cotton Belt: namely, Stoneville, Miss.; Knoxville, Tenn.; Greenville, Tex.; Florence, S. C.; Tifton, Ga.; and Baton Rouge, La. Seed of each of six varieties of cotton was divided into the necessary lots for planting at the various locations in 1941 and 1942. The six experimental varieties included the Seabrook variety of sea-island cotton (*Gossypium barbadense* L.) and the following varieties of upland cotton (*G. hirsutum* L.): Acala, Stoneville 37, Rowden 42A, Coker 100 (strain 3), and Farm Relief (strain 3). From 100 to 200 linear feet of row was planted to each variety at each location. The plots received the cultivation and fertilization normally used in the various localities.

Cotton was picked at definite intervals, starting 2 weeks after the beginning of opening and thereafter approximately every 14 days. After being harvested, the seed cotton was dried, if necessary, and stored in bags until all pickings were completed. Seed cotton from all locations was assembled at Knoxville, where 100-gm. subsamples were ginned on a small roller gin of the type regularly employed for ginning progeny material. Lint samples were conditioned at a constant temperature of 70° F. and 65 percent relative humidity before the physical properties of the fibers were determined.

INSTRUMENTS

The development of the fibrograph (*5*, *6*), Pressley strength tester (*14*), and arealometer (*3*, *17*), for the rapid measurement of length, length uniformity, strength, and fineness of cotton fibers, has made it practicable to obtain data on a relatively large number of fiber samples. These instruments are adapted for use with ginned cotton and were used in making the determinations reported in this study. The values given for the individual samples are the means of two measurements for length, two for length uniformity, four for strength, and two for fineness.

FIBROGRAPH

The fibrograph is a photoelectric instrument for scanning a fiber sample and tracing a special length and frequency distribution curve, or fibrogram, from which fiber lengths are readily obtained. A single fibrogram accurately estimates the length distribution of a population of approximately 150,000 fibers. Length values for the sample mean and for the longer half of the fiber population are obtained by the length of the intercepts made by tangents to the fibrogram.

The operation of the instrument is relatively simple, but a trained operator is required. A small amount of ginned lint (0.3 to 0.5 gm.) is taken at random from a fiber sample and placed upon one of a pair of combs. The fibers are then paralleled and freed of trash or other foreign matter by combing, being transferred from comb to comb several times. The combed sample consists of paralleled fibers evenly distributed over the length of the two combs, with the fibers caught at random points by the teeth and extending from the combs. The two combs bearing the fibers are placed in the fibrograph, and the fibrogram is traced directly upon a card by manipulation of the instrument. Fibers less than ¼ inch in length are not included in the values obtained. Measurements made with the fibrograph agree satisfactorily with those obtained by direct measurement of individual fibers. The length value obtained for the longer half of the fiber population (upper-half mean) is about the same as the cotton classer's staple length at $^{15}/_{16}$ inch but becomes progressively more conservative as length increases. An upper-half mean of $^{45}/_{32}$ inch is approximately equivalent to the classer's 1½-inch staple length. The sampling error for individual samples differs with the nature of the material. The coefficient of variation for the means of samples drawn from raw cotton, as estimated from duplicate measurements, is approximately 1.25. However, duplicate measurements of samples with well-mixed fiber such as may be found in mill roving have a coefficient of variation of approximately 1.1.

Two experienced operators, working with one instrument, can make approximately 100 determinations per day. Each analysis consists of sampling the raw cotton, preparing the combed sample, tracing the length-distribution curve, measuring the curve, and recording the mean and upper-half mean length. Customarily, duplicate fibrograms are made from each sample.

The length-uniformity index, as calculated from the two length values, is expressed as follows:

$$\frac{\text{Mean length}}{\text{Upper-half mean length}} \times 100.$$

This value may range from 65, for samples having a very high coefficient of variability for fiber length, to 85, for samples having a very low coefficient of variability. Although the relation between this index and the coefficient of variability is rather close, one is not readily converted into the other.

STRENGTH TESTER

The Pressley strength tester consists of a specially constructed pair of clamps, for holding a flat bundle or group of paralleled fibers, and a scale of the beam type, for determining the number of pounds required to break the bundle. A modification of Pressley's (*14*) technique for preparing the bundle of paralleled fibers has been adopted in the Knoxville laboratory. Ginned cotton is combed to parallel the fibers and arrange them at random, as for the fibrograph, and to remove neps, trash, or other foreign matter. This operation is identical with the preparation of the fibrograph sample, and in routine work the strength samples are taken from the fibrograph combs after the completion of the fibrogram.

By means of a spring clip with jaws approximately ½ inch wide, a group of the fibers extending from the comb is grasped at a point so that all fibers held extend at least as far as the thickness of the clamps. Adhering fibers not caught by the jaws of the clip are combed out. This paralleled group of fibers is then laid across the jaws of the breaker clamps and pulled taut without the part of the fiber to be broken being brought into contact with the fingers. The moisture content is not altered in the fiber to be broken; hence no further conditioning is necessary. The clamp jaws are closed and tightened. The tightness of the jaws has two important effects on the accuracy of the break. Insufficient tightening will allow some of the fibers to slip, resulting in a partial break. Variation in the degree of tightness affects the gage length (almost zero) between the clamps and may cause bias in the strength index. To eliminate operator differences, tightening is done while the clamp is held in a vise mounted on a rotary base. The clamp jaws are tightened against a spring tension, and the specified degree of tightness is maintained for all samples by all operators. Torque of 8.75 pound-inch on the clamp screws has been found adequate. After being tightened the clamps are removed from the vise and the fibers extending from the jaws are cut off even with the sides of the clamps. This reduces the sample to a standard length of approximately 0.460 inch. The number of pounds required to break the bundle of fibers is determined on the specially constructed beam scale. The broken fibers are removed and weighed. An index of comparative strength is obtained by the following equation:

$$\frac{\text{Pounds required to break}}{\text{Weight of fiber in milligrams}} = \text{strength index.}$$

Reliable determinations with the instrument are limited to samples having an upper-half mean length of more than ½ inch.

It should be pointed out that, since the density of cellulose is very nearly constant, the strength index is an approximate measure of breaking strength per unit of cross-sectional area, or tensile strength. Operator and machine inaccuracies limit the precision of the method. Clamps are not accurately standardized, and different sets seldom reach identical levels of measurement on standard cottons. With continued use, a gradual change in level of strength index may occur with any set of clamps, owing to change in the jaw surfaces. It is desirable to maintain standard samples for frequent calibration of the instrument. Strength-index readings may then be adjusted to a constant level for direct comparison of samples measured at any time.

One operator, working with samples previously combed for the fibrograph, can make approximately 200 single breaks per day. Four single breaks usually are made from each sample. A 4-break determination from raw cotton has a coefficient of variation approximating 1.55; with well-mixed fibers, as obtained from mill roving, about 1.35.

AREALOMETER

The arealometer is an instrument designed to measure the ratio of fiber surface to fiber volume or mass. The fiber surface per unit mass has been called the specific surface; in this paper it is expressed as square centimeters per milligram. The arealometer utilizes an aerodynamic principle governing the flow of gas through a porous medium. The resistance offered to air flow through fibrous material depends upon the area of exposed surfaces and the distances between these surfaces. As fibrous materials can be compressed to change the distances between surfaces uniformly throughout the fibre aggregation, the amount of compression required to give a known resistance to air flow is a convenient measure of the specific surface of fibrous material.

The term "specific surface" should be construed only as the measurement of the property specifically defined and not necessarily as a complete measure of the subjective property fineness, which has not been defined specifically in terms of physical properties. Arealometer determinations require only 100 mg. of lint for each reading, but the sample must be carefully drawn to be representative of the lot under test. A lint sample of 100 mg., free of trash or other foreign matter, is separated into a loose mass and rolled into a plug. This plug of fibers is inserted into a compression tube of standard bore. In the arealometer the plug is compressed until the resistance to air flow is equal to a standard resistance. The amount of compression, as indicated by the length of the plug, is read directly from the instrument. By means of a calibration chart, plug length can be converted to the specific surface in square centimeters per milligram. The present calibration chart covers the range 1.73 to 4.21 $cm.^2/mg.$ Fibers from strains of sea-island cotton frequently approach or exceed 4.21 $cm.^2/mg.$, and some of the special types of coarse cotton have values below the chart range of 1.73 $cm.^2/mg.$

A single operator can weigh out the fiber samples and make approximately 100 single readings per day. Customarily, two determinations

are made for each sample. The coefficient of variation for the mean of the two determinations approximates 1.8 for the averaged ginned sample, but for well-mixed cottons it approximates 1.3.

EXPERIMENTAL RESULTS

LENGTH

Fiber lengths of the different samples are given in table 1, and are tabulated to show the influence of variety, season, location, and picking date on variation in this character.

TABLE 1.—*Upper-half mean fiber length from successive pickings of 6 varieties of cotton at various locations in 1941 and 1942*

[All measurements in 1/32 of an inch]

Location and picking No.	1941							1942						
	(Sea-island brook)	Upland						(Sea-island brook)	Upland					
	Sea island	Acala	Stoneville 37	Rowden 42A	Coker 100	Farm Relief	Average	Sea island	Acala	Stoneville 37	Rowden 42A	Coker 100	Farm Relief	Average
Stoneville, Miss.:														
1	47.8	32.8	31.8	29.8	32.5	33.2	32.0	50.6	32.7	30.5	31.4	33.5	31.5	31.9
2	49.5	32.6	31.2	30.4	32.4	32.8	31.9	51.0	30.2	28.7	31.3	30.0	33.5	30.7
3	49.6	31.6	31.3	30.0	32.6	31.4	31.4	48.9	31.2	28.9	29.6	29.7	28.9	29.7
4	50.2	32.5	31.0	30.5	30.8	31.2	31.2							
Average	49.3	32.4	31.3	30.2	32.1	32.2	31.6	50.2	31.4	29.4	30.8	31.1	31.3	30.8
Knoxville, Tenn.:														
1		32.0	32.4	31.3	33.7	31.4	32.2		33.0	32.6	31.5	35.8	36.2	33.8
2	48.3	31.2	29.5	31.5	31.2	33.2	31.3	50.5	35.0	32.5	31.7	36.8	36.0	34.4
3	46.4	30.7	28.2	30.1	31.5	30.2	30.1	51.4	34.6	31.4	31.6	34.0	34.0	33.1
4	45.0	28.1	27.3	28.6	28.4	29.2	28.3	51.1	35.5	29.8	34.1	33.5	35.5	33.7
5	44.5							47.1	33.6	30.1	32.5	32.2	32.2	32.1
Average	46.1	30.5	29.4	30.4	31.2	31.0	30.5	50.0	34.3	31.3	32.3	34.5	34.8	33.4
Greenville, Tex.:														
1		31.0	31.2	29.4	30.3	28.9	30.2		31.3	30.1	29.2	32.7	30.9	30.8
2	42.9	31.3	29.1	30.7	29.5	29.9	30.1		30.3	28.7	29 2	28.9	30.4	29.5
3	41.8	30.3	28.3	28.9	27.5	30.5	29.1	44.3	28.4	30.4	28.8	28.7	29.6	29.2
4								43.8	31.2	29.2	29.2	29.9	33.5	30.6
Average	42.4	30.9	29.5	29.7	29.1	29.8	29.8	44.1	30.3	29.6	29.1	30.1	31.1	30.0
Florence, S. C.:														
1		30.6	28.8	29.5	31.8	30.5	30.2		30.8	30.7	30.0	28.3	28.5	29.7
2	43.7	30.9	28.7	28.5	28.8	31.1	29.6	49.5	30.4	29.0	30.1	31.8	29.9	30.2
3		30.0	27.6	27.4	28.0	27.5	28.1	49.1	32.3	29.1	28.8	31.6	31.0	30.6
4								48.8	33.1	29.8	28.4	31.7	32.5	31.1
Average	43.7	30.5	28.4	28.5	29.5	29.7	29.3	49.1	31.7	29.7	29.3	30.9	30.5	30.4
Tifton, Ga.:														
1	47.2	32.2	29.7	31.9	28.7	32.3	31.0		32.2	29.7	29.4	32.2	32.8	31.3
2	42.7	28.7	28.2	28.5	26.3	28.0	27.9	48.6	30.8	28.8	30.8	28.1	31.1	29.9
3								50.7	34.2	30.0	31.0	27.3	32.5	31.0
4								54.0						
Average	45.0	30.5	29.0	30.2	27.5	30.2	29.5	51.1	32.4	29.5	30.4	29.2	32.1	30.7
Baton Rouge, La.:														
1 [1]	42.4	28.9	28.7	28.3	27.6	29.2	28.5		30.0	30.3	29.7	32.5	30.3	30.6
2								53.7	30.7	30.2	30.7	28.9	33.1	30.7
3								53.1	31.7	31.7	31.5	33.6	33.5	32.4
Average	42.4	28.9	28.7	28.3	27.6	29.2	28.5	53.4	30.8	30.7	30.6	31.7	32.3	31.2
Average for variety	45.9	30.9	29.6	29.7	30.1	30.6		49.8	32.0	30.1	30.5	31.4	32.2	

[1] In 1941 all cotton was picked on Sept. 10.

Varietal differences are well known and need no discussion here. In general, the staple length of the upland cottons was greater in 1942 than in 1941, but seasonal conditions differed widely at different locations. For example, the average staple length of the upland cottons at Stoneville, Miss., was 0.8 thirty-seconds of an inch longer in 1941 than in 1942, whereas at Knoxville, Tenn., the same cottons were 2.9 thirty-seconds of an inch shorter in 1941 than in 1942. Different seasonal conditions may cause wide fluctuation in the fiber length of a single variety. Thus, Acala, the longest among the uplands, had an average length at Knoxville of 30.5 thirty-seconds of an inch in 1941 and 34.3 in 1942, a difference of 3.8 between the two seasons. The fourth picking of this variety in 1941 measured 28.1, as compared with 35.5 from a fourth picking in 1942, a difference of 7.4 thirty-seconds of an inch. Even wider ranges may be expected in long-staple cottons. Seabrook in 1942 averaged 44.1 at Greenville, Tex., as compared with 53.4 at Baton Rouge, La., a difference of 9.3 thirty-seconds of an inch. These are the extreme ranges in length, but such extremes are not unusual and illustrate the influence of environmental factors.

Comparisons of length at successive picking dates (table 1) show that fiber from early bolls may be either longer or shorter than fiber from late-season bolls. That is, fiber length may be markedly modified by climatic factors during the period of fiber development.

The varieties used in this study were not chosen primarily for differences in fiber length, and, with the exception of Seabrook, differed only slightly in this respect. All 5 upland varieties could be classed as $^{30}/_{32}$- to $^{32}/_{32}$-inch cottons. These average lengths, however, are derived from duplicate measurements on 39 samples of each variety collected at 6 locations and on various picking dates. Samples submitted by other experimenters to the fiber laboratory for study rarely have more than 3 or 4 replicates and in many cases none. Length values derived from unreplicated or poorly chosen samples cannot be expected to yield highly reliable information.

Environmental factors may cause length variations within a variety larger than the length differences normally expected between unlike strains and varieties under a single environment. It is highly important that environmental influences be recognized so that sampling methods may be adjusted to take account of such bias.

UNIFORMITY IN LENGTH

Cotton fibers are not of equal length, even on the same plant or on individual seeds. Substaple fibers are normally present on each seed and account for a large percentage of the length variation found in inbred or pedigreed cottons (*2*). As stated by Richmond and Fulton (*16*), the general concept of a uniform sample of cotton is of one in which a large proportion of the fibers are of the same length. Under this concept, lack of uniformity in lint cotton might be caused by an excessive proportion of substaple fibers on the individual seeds, by mixing of cotton from varieties of different lengths, by hybrid segregation, or by irregular seasonal and growth conditions differentially affecting the development of the fibers. The effects of seasonal conditions are largely fortuitous, but the proportion of substaple on

individual seeds is apparently a varietal characteristic and probably can be changed by breeding. From a study of fiber length in a strain of Pima cotton grown under irrigation where environmental differences were minor in character, Richmond and Fulton (*16*) found that the variation on individual seeds contributed 98 percent of the total variation in fiber length. Pope (*12*) concluded that the percentage of short fibers depends primarily on variety but is significantly modified by seasonal and soil differences.

Past methods of determining the amount of substaple have been either relatively crude and inaccurate, as by the hand-pulling method, or slow and tedious, as by the sorter array. Neither method is suitable for use where large numbers of progenies are analyzed in selecting breeding material. The fibrograph provides two measurements of length: the mean length of the entire sample and the mean length of the longer half (by weight) of the fiber, or upper-half mean. The percentage ratio between these two length measurements

$$\left(\frac{\text{Mean length}}{\text{Upper-half mean length}} \times 100 = \text{length-uniformity index}\right)$$

provides an index of length uniformity. Ware et al. (*18*) used this length-uniformity index in inheritance studies in upland cottons.

Data on length uniformity for six varieties of cotton, each grown at six locations in the Cotton Belt in 1941 and 1942, are shown in table 2. Rowden 42A, with an average length-uniformity index of 82.3, is definitely higher than any of the other varieties in this characteristic, while Coker 100 is generally low. The consistency in rank of the several varieties at the six locations and in both years demonstrates that length uniformity is a varietal characteristic. From the data of table 2, however, it is apparent also that genetic factors account for only a part of the variation in length uniformity. The length-uniformity indexes for five upland cottons grown at Stoneville, Miss., in 1941 averaged 80.4. The same five varieties grown at Baton Rouge, La., in 1941 had an average index of 71.5. In 1942 the respective averages were 77.4 at Stoneville and 78.5 at Baton Rouge. These data indicate that environmental factors, particularly seasonal and weather conditions, measurably affect the expression of this character. Variability within varieties at different locations and at successive pickings emphasizes the need for careful sampling to avoid differences due to environmental rather than hereditary factors.

FINENESS

Fiber fineness, as measured in this study, is expressed in terms of specific surface or surface area per unit weight of fiber (square centimeters per milligram). Data on specific surface from the material collected in 1941 and 1942 are presented in table 3. A fine-fibered cotton, as exemplified by Seabrook, is shown in table 3 as having had an average specific surface of +3.73[4] cm.^{2}/mg. The coarsest cotton was Rowden 42A, with an average of 2.25 cm.^{2}/mg. The hereditary

[4] Plus indicates that the measurements included samples finer than the machine calibration.

TABLE 2.—*Length-uniformity indexes of fiber from successive pickings of 6 varieties of cotton at various locations in 1941 and 1942*

Location and picking No.	1941							1942						
	(Sea-island) Seabrook	Upland: Acala	Stoneville 37	Rowden 42A	Coker 100	Farm Relief	Average	(Sea-island) Seabrook	Upland: Acala	Stoneville 37	Rowden 42A	Coker 100	Farm Relief	Average
Stoneville, Miss.:														
1	74.2	83.1	84.4	83.4	75.7	77.3	80.8	77.5	81.2	78.3	85.7	77.9	81.8	81.0
2	75.5	81.8	83.2	84.8	78.1	77.7	81.1	73.8	74.5	75.1	80.0	71.5	78.6	75.9
3	72.9	77.6	81.2	83.3	78.4	77.0	79.5	73.4	71.3	75.6	83.5	73.9	71.8	75.2
4	80.6	83.7	82.1	83.8	72.6	78.4	80.1	----	----	----	----	----	----	----
Average	75.8	81.6	82.7	83.8	76.2	77.6	80.4	74.9	75.7	76.3	83.1	74.4	77.4	77.4
Knoxville, Tenn.:														
1	----	81.4	81.2	86.3	72.3	72.3	78.7	----	75.8	81.6	84.4	77.8	84.1	80.7
2	78.1	75.9	79.0	84.6	71.7	73.6	77.0	77.3	78.1	83.4	88.6	76.5	81.7	81.7
3	75.1	71.5	78.7	81.9	70.9	73.5	75.3	70.6	73.7	81.2	83.7	74.8	75.6	77.8
4	76.3	70.9	77.7	75.6	72.1	70.1	73.3	76.4	80.1	78.2	84.9	79.7	76.2	79.8
5	73.9	----	----	----	----	----	----	73.5	78.6	77.5	83.7	79.5	73.3	78.5
Average	75.9	74.9	79.2	82.1	71.8	72.4	76.1	74.5	77.3	80.4	85.1	77.7	78.2	79.7
Greenville, Tex.:														
1	----	75.1	79.0	81.5	73.9	69.9	75.9	----	73.0	75.2	82.2	76.3	72.9	75.9
2	74.6	73.4	75.6	81.1	67.6	69.3	73.4	----	74.0	80.3	80.8	71.5	74.3	76.2
3	72.7	71.3	74.4	76.5	68.9	72.0	72.6	77.2	73.4	80.4	82.6	74.5	77.7	77.7
4	----	----	----	----	----	----	----	71.3	72.4	76.2	76.2	69.2	75.6	73.9
Average	73.7	73.3	76.3	79.7	70.1	70.4	74.0	74.3	73.2	78.0	80.5	72.9	75.1	75.9
Florence, S. C.:														
1	----	73.3	75.9	83.4	75.5	72.7	76.2	----	74.8	80.0	77.3	69.2	69.5	74.2
2	69.4	78.0	76.2	83.5	70.8	76.0	76.9	72.4	76.1	78.4	82.9	77.0	76.1	78.1
3	----	77.9	79.4	79.8	75.5	72.7	77.1	73.3	83.3	81.1	84.0	74.2	76.3	79.8
4	----	----	----	----	----	----	----	74.6	79.0	79.8	82.4	79.0	75.5	79.1
Average	69.4	76.4	77.2	82.2	73.9	73.8	76.7	73.4	78.3	79.8	81.7	74.9	74.4	77.8
Tifton, Ga.:														
1	72.5	80.1	77.9	83.8	68.9	75.1	77.2	----	78.2	82.0	85.2	74.5	73.1	78.6
2	69.3	75.1	75.0	76.9	71.1	71.5	73.9	75.5	75.6	75.1	83.6	71.3	75.9	76.3
3	----	----	----	----	----	----	----	74.5	70.9	78.1	77.3	71.6	76.6	74.9
4	----	----	----	----	----	----	----	77.4	----	----	----	----	----	----
Average	70.9	77.6	76.5	80.4	70.0	73.3	75.6	75.8	74.9	78.4	82.0	72.5	75.2	76.6
Baton Rouge, La.:														
1[1]	72.8	71.7	71.3	76.4	68.5	69.7	71.5	----	77.5	78.8	84.5	71.7	72.1	76.9
2	----	----	----	----	----	----	----	79.8	74.9	80.9	83.5	72.4	75.5	77.4
3	----	----	----	----	----	----	----	78.1	78.4	81.7	86.6	75.7	82.5	81.0
Average	72.8	71.7	71.3	76.4	68.5	69.7	71.5	79.0	76.9	80.5	84.9	73.3	76.7	78.5
Average for variety	74.1	76.6	78.4	81.6	72.5	73.5	----	75.1	76.1	79.0	82.9	74.5	76.2	----

[1] In 1941 all cotton was picked on Sept. 10.

nature of this fiber property is shown by the consistency in rank of Seabrook and Rowden 42A in both seasons and at all locations. The other varieties were intermediate between Seabrook and Rowden 42A in specific surface.

Environmental factors strongly affected the specific surface. Fibers produced at Greenville, Tex., and at Stoneville, Miss., in 1941 were definitely coarser than those from other locations. Fibers from Greenville were particularly coarse in 1942. In general, there was consider-

TABLE 3.—*Specific surface of fibers from successive pickings of 6 varieties of cotton at various locations in 1941 and 1942*

[Square centimeters per milligram]

Location and picking No.	1941 [1]							1942 [1]						
	(Sea-)	Upland						(Sea-)	Upland					
	Sea island brook)	Acala	Stoneville 37	Rowden 42A	Coker 100	Farm Relief	Average	Sea island brook)	Acala	Stoneville 37	Rowden 42A	Coker 100	Farm Relief	Average
Stoneville, Miss.:														
1	3.45	2.83	2.95	2.17	2.61	2.71	2.65	3.49	2.69	2.74	2.36	2.61	2.21	2.52
2	3.49	2.79	3.22	2.19	3.15	2.58	2.79	3.88	2.70	3.40	2.20	3.16	2.61	2.81
3	3.61	2.60	3.05	2.15	2.92	2.56	2.66	3.67	2.81	2.88	1.96	3.07	2.64	2.67
4	3.70	2.72	2.59	1.93	2.95	2.41	2.52	----	----	----	----	----	----	----
Average	3.56	2.74	2.95	2.11	2.91	2.57	2.66	3.68	2.73	3.01	2.17	2.95	2.49	2.67
Knoxville, Tenn.:														
1	----	2.60	2.79	2.04	2.87	2.78	2.62	----	2.55	2.93	2.10	2.55	2.36	2.50
2	3.71	3.15	2.86	2.31	3.06	2.85	2.85	3.65	2.79	2.75	2.18	2.97	2.42	2.62
3	3.62	3.00	3.04	2.55	3.41	3.15	3.03	3.84	2.88	2.76	2.11	2.98	2.65	2.68
4	3.76	3.48	3.25	2.91	3.42	3.44	3.30	4.01	3.13	3.05	2.34	3.12	2.87	2.90
5	4.14	----	----	----	----	----	----	+4.21	4.02	3.33	2.36	3.24	3.55	3.30
Average	3.81	3.06	2.99	2.45	3.19	3.06	2.95	+3.93	3.07	2.96	2.22	2.97	2.77	2.80
Greenville, Tex.:														
1	----	2.66	2.73	2.22	2.82	2.54	2.59	----	3.29	2.93	2.23	2.83	2.74	2.80
2	3.95	2.82	2.43	2.22	2.87	2.46	2.56	----	2.45	2.27	2.08	2.76	2.63	2.44
3	4.02	2.79	2.80	2.49	3.09	2.95	2.82	3.52	2.43	2.08	1.90	3.06	2.27	2.35
4	----	----	----	----	----	----	----	3.64	2.49	2.23	2.11	2.58	2.06	2.29
Average	3.99	2.76	2.65	2.31	2.93	2.65	2.66	3.58	2.67	2.38	2.08	2.81	2.43	2.47
Florence, S. C.:														
1	----	3.46	2.98	2.66	3.27	2.95	3.06	----	2.76	2.84	2.16	3.00	2.72	2.70
2	4.12	2.50	2.77	2.48	3.37	2.74	2.77	3.75	2.52	2.68	2.03	2.62	2.59	2.49
3	----	2.51	2.73	2.17	2.85	2.53	2.56	3.47	2.47	2.42	2.09	2.73	2.32	2.41
4	----	----	----	----	----	----	----	3.69	2.32	2.47	1.93	2.51	2.62	2.37
Average	4.12	2.82	2.83	2.44	3.16	2.74	2.80	3.64	2.52	2.60	2.05	2.72	2.56	2.49
Tifton, Ga.:														
1	4.15	2.78	2.70	2.58	4.00	2.73	2.96	----	2.20	2.65	1.92	3.38	2.21	2.47
2	+4.21	2.71	3.59	2.89	+4.21	4.17	+3.51	3.27	2.73	2.96	1.86	3.49	2.35	2.68
3	----	----	----	----	----	----	----	3.66	3.11	2.57	2.32	3.92	2.67	2.92
4	----	----	----	----	----	----	----	3.56	----	----	----	----	----	----
Average	+4.18	2.75	3.15	2.74	+4.11	3.45	+3.24	3.50	2.68	2.73	2.03	3.60	2.41	2.69
Baton Rouge, La.:														
1 [2]	3.34	3.11	3.04	2.30	+4.21	2.98	+3.13	----	2.64	2.69	2.07	2.85	2.34	2.52
2	----	----	----	----	----	----	----	3.36	2.45	2.75	2.47	3.18	2.62	2.69
3	----	----	----	----	----	----	----	3.44	2.79	2.47	2.14	2.99	2.38	2.55
Average	3.34	3.11	3.04	2.30	+4.21	2.98	+3.13	3.40	2.63	2.64	2.23	3.01	2.45	2.59
Average for variety	3.81+	2.85	2.91	2.37	3.24+	2.85	----	3.65+	2.74	2.72	2.13	2.98	2.54	----

[1] Plus indicates that the measurements included samples finer than the machine calibration.
[2] In 1941 all cotton was picked on Sept. 10.

able similarity in the behavior of the several varieties at different locations; that is, all varieties tended to be coarser or finer as influenced by environment. All varieties, however, were not affected to the same degree; for instance, Coker 100 showed considerably more variability than other varieties, as evidenced by its behavior at Tifton, Ga., and Baton Rouge, La. It is difficult to explain the extreme fineness of the Coker 100 fiber at these two locations in both 1941 and 1942. If the

evidence were limited to the data from Tifton, Ga., in 1941 and 1942, one might draw the erroneous conclusion that Coker 100 and Seabrook were of equal fineness. The environmental influence on specific surface is so great that genetic factors may be completely masked if only a few samples are examined.

Position of the bolls on the plant, as indicated by date of opening, apparently had no consistent effect on fineness of fiber at locations where there was ample time for boll maturation. Variation in fineness occurred between successive pickings, but there was no definite trend toward finer or coarser fiber as the season advanced. This was not true, however, at Knoxville, Tenn., where the short growing season prevented full maturity of late-season bolls. At Knoxville, in both 1941 and 1942, fibers were progressively finer as the picking date advanced. In many cases the variation in fineness within a variety due to variation in picking date exceeded the average difference between upland varieties at a given picking date. Since the specific surface is derived from the relation between surface area and weight, thin-walled fibers would be classed as fine by the arealometer method. Underdevelopment due to stress conditions or immaturity may arrest normal wall thickening and result in fibers having high specific surfaces.

STRENGTH

Tensile strength of cotton fibers has received increasing attention from cotton breeders as methods for the rapid measurement of this property have been developed. The cotton-fiber strength tester developed by Pressley (*14*) has proved particularly useful to cotton breeders and others interested in relative tensile strength. Tensile strength is recognized as hereditary. Pressley (*14, p. 13*) states: "Highly significant differences were found between plants of individual progeny rows, while the lint of some varieties was found to be practically twice as strong as that of others."

Varietal, locational, and seasonal effects on strength index of the samples collected in 1941 and 1942 are shown in table 4. Wide hereditary differences in strength between varieties are well illustrated by comparison of Seabrook with the upland varieties. Seabrook is consistently the strongest cotton at all locations in both years.

Farm Relief had the highest average strength index of the upland varieties, but the data are too inconsistent to establish any real difference between the other uplands. For the upland varieties as a whole, environmental factors had far more influence in determining fiber strength than did genetic differences. In both years, cotton produced at Greenville, Tex., was outstandingly stronger than that from other locations. At Greenville, the cotton produced in 1942, in general, was stronger than that produced in 1941. The cottons from Greenville were also the coarsest. The cotton produced at Knoxville was relatively weak and also relatively fine.

The widest variations in strength within variety occurred at Florence, S. C., and Baton Rouge, La. At these two locations, heavy rains occurred during the harvesting period and exposure to adverse weather may have caused deterioration in fiber strength. Other data have shown that field exposure, particularly in rainy weather, will cause rapid deterioration in fiber strength.

TABLE 4.—*Strength indexes of fiber from successive pickings of 6 varieties of cotton at various locations in 1941 and 1942*

Location and picking No.	1941							1942						
	(Sea-island brook)	Upland						(Sea-island brook)	Upland					
	Sea island brook)	Acala	Stoneville 37	Rowden 42A	Coker 100	Farm Relief	Average	Sea Island brook)	Acala	Stoneville 37	Rowden 42A	Coker 100	Farm Relief	Average
Stoneville, Miss.:														
1	10.40	6.70	6.75	6.81	6.63	6.74	6.73	10.16	7.15	7.49	7.30	6.69	7.74	7.27
2	9.83	7.17	6.81	6.78	6.57	7.41	6.95	10.48	7.37	7.27	6.68	7.07	7.63	7.20
3	10.20	6.60	6.62	7.29	6.61	7.52	6.93	10.19	7.09	7.48	6.69	7.24	7.22	7.14
4	10.14	6.80	7.16	7.20	6.92	6.84	6.98	----	----	----	----	----	----	----
Average	10.14	6.82	6.84	7.02	6.68	7.13	6.90	10.28	7.20	7.41	6.89	7.00	7.53	7.21
Knoxville, Tenn.:														
1	----	6.23	6.60	7.01	6.82	7.10	6.75	----	5.70	6.15	5.71	6.03	6.34	5.99
2	10.35	6.79	6.58	7.24	7.17	6.88	6.93	9.27	6.00	5.97	5.89	6.61	6.35	6.16
3	10.05	7.78	6.90	7.08	7.51	7.21	7.30	9.63	6.16	6.27	5.52	6.65	6.73	6.27
4	9.57	7.40	7.41	7.68	6.98	7.67	7.43	9.57	6.37	6.33	6.33	7.13	6.96	6.62
5	9.92	----	----	----	----	----	----	9.26	6.14	6.80	6.36	6.35	6.64	6.46
Average	9.97	7.05	6.87	7.25	7.12	7.22	7.10	9.43	6.07	6.30	5.96	6.55	6.60	6.30
Greenville, Tex.:														
1	----	8.22	7.24	7.67	8.19	8.30	7.92	----	9.21	7.87	8.44	8.31	8.47	8.46
2	10.16	7.55	7.16	7.79	7.50	8.78	7.76	----	9.07	7.82	8.41	8.12	8.21	8.33
3	9.64	8.02	7.08	7.31	7.73	8.87	7.80	10.17	8.77	7.55	7.76	8.31	7.90	8.06
4	----	----	----	----	----	----	----	9.57	8.25	7.77	7.52	7.99	8.72	8.05
Average	9.90	7.93	7.16	7.59	7.81	8.65	7.83	9.87	8.83	7.75	8.03	8.18	8.33	8.22
Florence, S. C.:														
1	----	6.56	6.68	6.20	6.93	6.39	6.55	----	5.58	6.19	5.65	6.26	5.10	5.76
2	9.68	6.55	6.56	6.23	6.71	6.80	6.57	10.48	6.91	6.48	6.99	6.48	7.20	6.81
3	----	7.15	6.91	7.03	7.12	7.19	7.08	9.87	7.13	6.31	7.27	6.90	6.92	6.91
4	----	----	----	----	----	----	----	9.69	7.17	6.15	7.01	6.32	6.63	6.66
Average	9.68	6.75	6.72	6.49	6.92	6.79	6.73	10.01	6.70	6.28	6.73	6.49	6.46	6.53
Tifton, Ga.:														
1	10.09	7.12	6.61	7.16	6.84	7.56	7.06	----	7.71	8.34	7.12	7.26	8.68	7.82
2	10.40	6.40	6.87	7.20	6.34	6.72	6.71	10.39	7.59	8.26	7.19	7.07	7.43	7.51
3	----	----	----	----	----	----	----	10.19	7.35	7.53	7.44	7.57	7.67	7.51
4	----	----	----	----	----	----	----	9.96	----	----	----	----	----	----
Average	10.25	6.76	6.74	7.18	6.59	7.14	6.88	10.18	7.55	8.04	7.25	7.30	7.93	7.61
Baton Rouge, La.:														
1 [1]	10.12	7.37	6.46	7.58	6.52	7.44	7.07	----	6.21	6.75	6.02	6.84	6.70	6.50
2	----	----	----	----	----	----	----	10.14	6.57	6.86	7.52	6.51	7.96	7.08
3	----	----	----	----	----	----	----	10.08	7.15	7.12	7.27	6.96	7.06	7.11
Average	10.12	7.37	6.46	7.58	6.52	7.44	7.07	10.11	6.64	6.91	6.94	6.77	7.24	6.90
Average for variety	10.04	7.08	6.85	7.13	7.01	7.38	----	9.95	7.12	7.03	6.91	7.03	7.28	----

[1] In 1941 all cotton was picked on Sept. 10.

DISCUSSION AND CONCLUSIONS

No attempt has been made in this paper to show specific effects of environmental factors on the length, uniformity of length, fineness, and strength of fibers. Extensive physiological studies would be necessary to establish these relations. The data presented here are measurements of fiber properties from samples grown under a wide range of conditions. Through precise laboratory methods variations

due to genetic and environmental factors are clearly shown. Plant breeders and others interested in the study of fiber properties may well be forewarned that samples for fiber study must be taken with great care if minor genetic differences are to be detected. Differences between samples in fiber properties may be due as much to location or date of picking as to variety or genetic strain.

For many years the progress and scope of cotton-breeding programs have been limited by lack of facilities and tools for the accurate measurement of the physical properties of cotton fiber. Information, particularly on length uniformity, fineness, and strength, has been so limited that even now the interrelated effects of these characters on spinning value and yarn strength are not clearly understood.

The fibrograph, arealometer, and Pressley strength tester are important additions to our laboratory equipment. These instruments are capable of accurate measurement of minor differences in fiber properties and have sufficient capacity to admit of determinations on large numbers of samples.

Control of laboratory conditions and perfection of laboratory technique have reduced the machine and operator errors of measurement to very narrow limits. Proper interpretation of the results of fiber determinations is dependent upon knowledge of sample history. Variability such as has been shown in the preceding tables will vitiate the conclusion no matter how accurate the instruments, unless the samples submitted to the laboratory are of comparable growth and field history.

Environmental factors may completely mask hereditary influence unless the effects of these extraneous factors are minimized. This can be accomplished by refinement in sampling technique. Comparable lint samples are most likely to be obtained from bolls that developed during the same growth period and were picked without undue exposure in the field. Samples picked from plants after most of the bolls have opened may include cotton from early and late bolls, with consequent differences due to development period and length of field exposure. Also, some individual plants may be represented by samples from early bolls and others from late bolls, with resulting differences in fiber properties principally due to environmental factors. In many cases, plant selections based upon such differences will fail to produce the desired improvement.

Wide variations in physical properties of fiber due to season draw attention also to the possibilities of losing valuable breeding material if such material is discarded on the basis of 1 year's test. Even with the most meticulous field sampling seasonal variation cannot be avoided, but such variation can be recognized and allowed for if adequate check samples of a variety of known value are carried.

The effects of locational and environmental factors themselves are important in the study of the physical properties of cotton fibers. More information is needed regarding the influence of soil and weather on fiber growth and development. In this study, it was not apparent why cotton from Greenville, Tex., was coarse and strong as compared with cotton from other locations, or why cotton at Knoxville, Tenn., averaged $\frac{3}{32}$ of an inch longer in 1942 than in 1941.

SUMMARY

Seed cotton samples were obtained from six varieties of cotton grown at six locations in the Cotton Belt in 1941 and 1942. At each location, pickings were made at regular intervals so that the samples represented the production during definite growth periods. Length and uniformity in length, fineness, and strength of fiber in these samples were determined by the fibrograph, arealometer, and Pressley strength tester, respectively.

Factors involving change of environment, such as location, date of opening, or year of growth, caused wide variation in the physical properties of the fiber of the several varieties. Among the upland varieties, variation within variety due to environment frequently exceeded the differences between varieties due to hereditary influence. Without extreme care in field sampling, environmental factors may introduce bias sufficient to mask heritable qualities and vitiate conclusions drawn from accurately measured samples.

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